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PLANT INDICATORS OF SOIL TYPES[1]

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HISTORICAL

Development of the idea of plant indicators

From ancient times more observant people have associated certain plants with definite soil conditions as indicators of that condition. Thus Cato, bluff farmer-statesman, notes those growing on good wheat land while Pliny (16) records these as "dwarf elder, wild plum, rubus, plants which develop 'bulbs,' trefoil, oak, wild pear and apple." About the same time, at the opening of the Christian era, Columella (3) adds "rushes, reeds, grass, clover, and other plants known to search for water and sweetness." All of these plants do not indicate good wheat land with us but show that correlation between soil and flora was early established. Similar ideas were held throughout the Middle Ages and were transferred to the New World by those early settlers who were Classicists as well as farmers.

The scientific aspect however developed after plant physiology had its beginning, and we note among those early workers King, 1685; Degner, 1729; Buffon, 1742; and Biberg, 1749. The importance of plant indicators was suggested by Linné, 1751; emphasized by Heldenberg, 1754; while Schuow, 1832, classified them by habitats. During the nineteenth century two schools of thought arose, those who emphasized chemical influence of soil (Nageli, Contejean, Hilgard, and Schimper) and those who believed in the physical theory founded by Thurmann, 1849.

Much of the work on plant indicators has been done in this country and within the last two decades. One of our pioneer investigators was Edmund Ruffin (17) of Virginia, who contrasted the pines and andropogon of shelly lands with black locust, hackbeery, and pawpaw of rich river margins, and noted that "trees which thrive on one class are seldom found on the other, or if found, are stunted." Hilgard in his work on plant indicators stressed size, form and relative development of a plant association. Chamberlain, 1871, emphasized importance of the community as a unit in observation rather than a species. At the end of the century, 1898, Merriam summed up existing knowledge, and though his studies were based on temperature yet his efforts in bringing together facts from remote sources stimulated all branches

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of ecology. Hilgard, 1906, next stressed relation of plants to lime and to water while Clements, 1910, correlated certain plants with soil adapted for crops. Next year Shantz's publication demonstrated use of the quadrat method. Later, in 1917, he used plant types as indicators of soil conditions, making these a basis of classification of government lands. Weaver, 1919, noted the significance of roots as indicators.

Classification of plant indicators

After a definite relation had been established between certain plants and the soils upon which they grew, attemps were made to classify these plants. Contejean proposed relation to lime as a criterion, dividing plants into three groups: calciphile (lime-loving), calcifuge (lime-hating), and indifferent. While certain species are undoubtedly calciphile or calcifuge yet objections have been raised to this classification since a species growing upon a soil lacking in lime is not necessarily calcifugous. Thus White (24) and Pipal (15) have shown that sorrel (*Rumex acetosella*) grows on sour soil because there it has less competition; it grows luxuriantly on lime soil if not choked by other plants. The criterion was changed to relative acidity with the three classes acid-tolerant, acid-intolerant and indifferent. The objection has been made to this classification that it would seem to indicate actual destruction of plant tissues by the soil acid. Soil acids do not attack root tissues but interfere with physiological activities of metabolism.

Tolerance was naturally applied first of all to crop plants and Coville (5) has been an ardent investigator in this field. He has shown that certain plants may thrive in acid soils(sixteen species including strawberry, potato, corn and oats), while others (as alfalfa) die in an acid soil no matter how fertile. Intolerance is not a family but a species character for legumes other than alfalfa, as cowpea or hairy vetch, produce heavy growth in acid soil. Detailed studies on some species were made in their relation to hydrogen-ion concentration similar to that of Joffe (12) on alfalfa until Truog (20) was able to list sixty-two species, mostly cultivated which showed relative tolerance.

Attention had been paid to economic plants and even in the woods trees alone were taken into consideration as indicators. These, of course, indicate subsoil conditions, so that it remained for Cajander, 1909, to point out the importance of ground cover or undershrubs as indicative of soil conditions beneath. In forests of Germany he was able to work out a satisfactory classification. Later workers correlated forest types with agricultural possibilities and with the relations of water, light and fire. Korstian, 1917, noted that growth of a dominant tree is the best indicator of the quality of a forest site.

Specificity of plants to soil types

Previous work had shown that species may be associated definitely with certain kinds of soil. Even the untrained had developed the proverb that"a limestone country is a rich country." Even some apparent exceptions have been shown to be apparent only. Thus Wherry (22) in studying the walking-fern (*Camptosorus rhizophyllus*) found locaties as at Lewisburg where the plant grew on slate soil, normally acid, while the plant is a calciphile. Upon chemical examination it was found that the soil in which the roots grew was alkaline rather than acid. The walking fern is designated as specific to alkaline soil.

But comparatively little work has been done in correlation of plant forms with soil types: "a soil type is a soil which throughout the area of its occurrunce has the same texture, color, structure, character of subsoil, general topography, process of derivation and derivation from the same material" (19). Some studies have included soil types as that of Fred and Graul (7) with Colby silt loam and Plainfield sand in Wisconsin; of Bear (2) with Dekalb silt loam, West Virginia, and Wooster silt loam, Ohio; and of Gillespie and Hurst (8) on Caribou and Washburn loams in Maine. Pennell (13,14) has given an admirable study of the Conowingo Barrens of Chester county, Pa., and lists plants confined to the Barrens, noting also the

distinction between the xerophytic flora of the ridges and the more mesophytic flora of the clay regions adjoining. Sharp and Hoagland (18) tested a variety of soils with the hydrogen electrode, finding a range of pH values of 3.7 to 9.7.

OBJECT

The writer has had for his object the determination whether a general hydrogen-ion concentration, or "mode" (9), may be assigned to each of the soil types of southeastern Pennsylvania, and whether a definite relation exists between these soils and the flora growing upon them.

SOIL TYPES

The region studied is that portion of Chester County lying within a four-mile radius about Paoli; it is dominated by the Chester Valley, which is bounded on either side by low ranges of hills running northeast and southwest, and the soil areas have the same general trend. The soils are almost all upland residual and belong to that region where the Coastal plain passes into the Piedmont. There are three small areas of Pensauken formation in the Valley and some meadow is found but most of the soils are residual from Palaeozoic rocks. From north to south we meet the following belts of loam [For a more detailed description see Bascom (1)]:

1. Chester loam. This loam forms extensive tracts north and south of the Valley Hills consisting of hilly land with alternate woods and farms, the fields of which are so steep in cases as to be troubled with washing; there are numerous streams and the larger ones flow through narrow wooded valleys often of wild beauty. The surface soil is yellow brown with yellowish subsoil and contains scattered rounded boulders seen on the surface especially in pastures along streams. It is "derived from igneous and metamorphic rocks, principally from gneiss and mica schists with considerable areas from gabbro-diorite and other igneous rocks" of Pre-Cambrian age (19). Analysis of Wissahickon mica-gneiss showed the following content:

	per cent		per cent
SiO_2	66.13	FeO	3.19
Al_2O_3	15.11	MgO	2.42
Fe_2O_3	2.52	MnO	0.20

2. Dekalb loam. Derived from Chickies quartzite, this loam chiefly covers the North Valley Hill and in places, especially on the Valley Forge hills, becomes colluvial. Here as on Mount Joy and Mount Misery the slopes are inclined forty degrees with the horizontal and are composed of irregular slates between which are pockets of soil supporting a rather sparse growth of undershrub and scattered trees. The soil is a loam from Cambrian sediments, light, often gray, with yellow subsoil and is distinctly sandy; it is relatively high in aluminum and iron:

	per cent		per cent
SiO_2	56.35	CaO	0.19
Al_2O_3	23.21	Mn	trace

3. Hagerstown loam. This occupies the Chester Valley and is derived from Shenandoah limestone of Ordivician times; the soil is rich brown with yellow clay subsoil. The valley is three miles wide at its greatest width and its floor is of uneven contour, containing stretches of flat land with sinks and numerous streams which often have steep rocky banks. Most of the land is farmed and there are but few areas of woodland. Near the South Valley Hill the limestone becomes admixed with feldspar to form bastard limestone and a rather different type of soil. There also appear near this ridge several lenticular hills of micaceous schist synclinal or intercalated in the limestone. The following analysis was made of some typical valley limestone:

	per cent		per cent
SiO_2	24.23	$CaCo_3$	40.27
Al_2O_3	1.12	$MgCo_3$	31.24
Fe_2O_3	1.06		

4. Manor loam. Overlying the South Valley Hill this loam is residual from Octoraro schists of Ordivician time. The surface soil is yellow becoming, in contrast to most soils, dark with cultivation; it contains mica particles and small fragments of slate while the subsoil is often deep red. A typical analysis is the following:

	per cent		per cent
SiO_2	39.35	FeO	9.00
Al_2O_3	31.92	CaO	
Fe_2O_3	2.19	MgO	3.08

These hills are lower than the North Valley Hills and are indented by many stream-ravines. In these ravines is found a rich brown soil overlying the usual yellow subsoil, a loam differing from other portions of the Manor series not only in physical appearance but in the flora growing upon it, and the writer has therefore distinguished it as Manor Valley loam. Frequently swamps occupy these ravines and then acid rather than alkaline conditions prevail.

Upon the hills the soil becomes very thin, the slates larger and more abundant with jutting ledges of schist and quartz; this soil is called Manor stony loam.

5. Conowingo loam. South of the Valley Hills lies a long uneven descending slope in which Manor soil gives place to Chester loam. Across this portion of the Chester series runs a part of the Conowingo Barrens, represented by a few low ridges with a wide area of clay on either side. This loam is "rich in iron-magnesium silicates but almost lacking in lime, potash or other desirable constituents." In this study the clay is considered as Conowingo loam; the ridges are more acid.

METHOD

These soil types were tested for acidity by the colorimetric method. The process used at first was that described by Wherry (23). All tests were made in the field to avoid possible changes in acidity.

Modifications of the method were soon found necessary however. To assure comparable results similar quantities of material must be used; volume was used as a criterion rather than weight. Levels of 5 and 15 cc. of water were marked on the test tubes employed, soil being lightly compacted to the 5-cc. level and water being added to the 15-cc. level, the tube thoroughly shaken and then allowed to stand until the suspension had settled (often requiring considerable time).

Comparison of color produced by the color indicator with that on the chart published by Dr. Wherry did not prove satisfactory and it is hoped to continue the work with glycerophosphate buffers of a 0.2 interval.

First tests did not allow for carbon dioxide content of the soil solution. In conversation with the writer Dr. Osterhout suggested that carbon dioxide might have considerable influence on a soil test. Apparatus was prepared which could be readily carried into the field: air is passed through a NaOH tube into a vial containing a sample of the soil solution with two drops of indicator, a glass trap being interposed between the U-tube and the vial. Cotton plugs placed in the arms of the U-tube and of the trap prevent passage over of NaOH. With these precautions no change could be detected in the pH value. This result is in accord with Hoagland and Sharp (11) who state that, as a result of their experiments, "no permanent change in soil reaction could be attributed to the carbon dioxide."

Experiments were first made with topsoil which, of course, gave results indicative primarily only of soil conditions for herbs. To discover conditions in the subsoil samples were taken with which a soil auger consisted of a $1\frac{1}{2}$-inch wood auger fastened to sections of gas pipe which could be uncoupled with wrenches and carried in a case in the field. Borings with this auger may be made up to ten feet, though most of the soils were not so deep and in Manor stony loam no borings could be made, for here the loam is decidedly minor to slates and jutting ledges of rock. Care must be taken to prevent contamination of the sample as the auger is drawn out of the boring.

RESULTS

From determinations made by the colorimetric method an average reaction was derived for each soil type:

SOIL TYPE	pH VALUE
Hagerstown	7.2
Manor valley	7.2
Conowingo	7.1
Chester	7.0
Manor	6.6
Dekalb	6.2
Manor stony	5.75

These values are simply averages for the whole area covered by each loam; particular localities may have a reaction varying by a factor of $\pm\sqrt{10}$ (pH 0.5) or even more in a few cases from causes noted below.

The values given represent surface soil conditions. Some borings have been made into the subsoil with the soil auger but not enough data is accumulated to formulate conclusions as to its acidity.

TABLE 1

Plants characteristic of the soil types

TREES	SHRUBS	HERBS
Hagerstown loam		
†*Juniperus virginianum*	*Corylus americana*	**Pellaea atropurpurea*
Quercus alba	*Celastrus scandens*	**Camptosorus rhizophyllus*
Ulmus americana	*Staphylea trifolia*	*Epuisetum hyemale* .
*Celtis occidentalis		*Asarum canadensis*
Lirodendron tulipifera		*Aquilegia canadensis*
Platanus occidentalis		*Dicentra cucullara*
Negundo aceroides		*Mitella diphylla*
Fraxinus americana		
Manor valley loam		
Ostrya virginiana	*Benzoin aestivale*	*Osmunda cinnamonea*
Lirodendron tulipifera	*Hamamelis virginiana*	*Lycopodium annotinum*
Prunus pennsylvanica	*Vaccinium corymbosum*	*Erythronium americanum*
*Fraxinus pennsylvanica var.		*Medeola virginiana*
lanceolata (in swamps)		*Euonymus obovatus*
		Viola scabriuscula
		Panax trifolium
		*Trientalis americana
		Collinsonia canadensis
		Aster divaricatus
Conowingo loam		
Juniperus virginianum	*Smilax rotundifolia*	*Andropogon scoparius*
*Quercus stellata		**Paspalum pubescens*
Acer rubrum		**Cerastium oblongifolium*
		Viola fimbriatula
		*Aster depauperatus
Chester loam		
Carya ovata	*Amalenchier canadensis*	*Lillum superbum*
Quercus rubra	*Rhus glabra*	*Smilax herbacea*
Q. coccinea		*Iris versicolor*
Q. velutina		*Houstonia cerulea*
Ulmus americana		*Specularia perfoliata*
Prunus americana		*Solidago rugosa* .
Cornus florida		
Fraxinus americana		

TABLE 1—*Concluded*

TREES	SHRUBS	HERBS
	Manor loam	
Carya alba	Rhus copallina	Pteris aquilina
C. cordiformis	Viburnum acerifolium	Andropogon scoparius
Betula lenta		*Gillenia trifolia
Castanea dentata		Viola pubescens
Sassafras variifolium		*Solidago polycephala
Robinia pseudo-Accaia		Aster ericoides
	Dekalb loam	
Carya ovata	Smilax rotundifolia	Iris versicolor
C. alba	Amelanchier oblongifolia	Cassia marilandica
Quercus nana	Rhodendron nudiflora	Viola fimbriatula
*Q. illicifolia	Vaccinum corymbosum	Veronica officinale
	Symphorocarpus vulgaris	Solidago pubescens
	Manor stony loam	
Castanea dentata	Kalmia latifolia	Polypodium vulgare
*Quercus prinus	Gaylussacia baccata	Andropogon glomeratus
	Rhododendron nudiflora	Cassia nyctitans
		Epigea repens
		Seriocarpus asteroides

* Species marked by an asterisk are almost entirely confined to soil type.

† Plants in both tables are arranged according to the classification in the seventh edition of Gray's Manual.

During the winter it was found that falling snow is neutral in reaction and continues neutral for several days or as long as it remains in the open country. In proximity to steam railroads, however, snow became covered with fine cinders in a few hours and the reaction changed from neutral to a pH value of 4.5 or 4. Since this cover of cinders is quite uniform and extends for about a mile on either side of the railroad, depending upon the wind, the acidity of these regions would probably be affected.

Contrast of winter with summer conditions has been studied but not enough tests have been made to establish definite conclusions. Those made indicate a higher degree of acidity in late summer, especially in such types as the Conowingo. This would be expected since these types have either a thin layer of loam on bedrock or too great a subsoil drainage; the flora is sparser and less moisture is conserved. Vegetable decay is then halted and a more acid leaf mold results.

The relation of these results to the flora growing upon the different loams is shown in the accompanying tables. It will be seen from table 1 that certain plants are characteristic of each of the different soil types, and that species of the same family may be characteristic of widely different types of soil.

TABLE 2

Plants found on the different soil types

NAME OF PLANT	HAGERSTOWN	MANOR VALLEY	CONOWINGO	CHESTER	MANOR	DEKALB	MANOR STONY
Pteridophyta							
Polypodium vulgare L.	−*	−	−	+	−	+	+
Pteris aquilina L.	−	−	+	+	+	+	−
Pellaea atropurpurea Link	+	−	−	−	−	−	−
Asplenium platyneuron (L) Oakes	+	+	+	+	+	+	−
Camptosorus rhizophyllus Link	+	−	−	−	−	−	−
Polystichum acrostichoides Schott	+	+	(+)	+	+	+	−
Aspidium marginale Sw	+	+	(+)	+	+	+	−
Onoclea sensiblis L.	+	+	+	+	+	+	−
O. cinnamonea L.	−	+	(+)	+	−	+	−
Botrichium virginianum Sw.	+	+	+	+	+	+	−
Equisetum arvense L.	+	+	−	−	+	−	−
E. hyemale L.	+	−	−	−	−	−	−
Lycopodium complanatum L.	−	−	−	−	(+)	+	−
L. annotinum L.	−	+	−	+	(+)	+	−
var. *flabelliforme* Fernaid	−	−	−	+	+	+	−
Spermatophyta							
Juniperus virginianum L.	+	(+)	+	+	+	+	(+)
Tsuga canadensis L.	−	−	−	−	−	+	+
Andropogon glomeratus BSP.	−	−	−	−	(+)	−	+
Andropogon scoparius L.	−	−	+	−	+	+	−
Arisaema triphyllum Schott	+	+	−	+	+	(+)	−
Veratrum viride Ait.	−	+	−	(+)	−	(+)	−
Uvularia perfoliata L.	−	+	−	+	+	+	−
Lillium superbum L.	−	−	−	!	−	−	−
L. canadensis L.	−	−	−	!	−	+	−
Smilacinia racemosa (L) Desf.	+	+	−	+	+	+	−
Maianthemum canadense Desf.	+	+	(+)	+	+	(+)	−
Medola virginiana L.	+	+	−	+	−	(+)	−
Smilax herbacea L.	+	+	−	+	+	+	−
S. rotundifolia L.	−	−	!	+	+	+	−
Iris versicolor L.	−	−	−	+	−	+	−
Cypripedeum acaule Ait.	−	−	−	−	+	+	−
Julans cinerea L.	+	+	−	−	+	−	−
J. nigra L.	!	+	(+)	+	+	+	−
Carya ovata (Mill) K. Koch	−	−	−	+	−	+	−
C. alba (L) K. Koch	+	+	−	−	+	+	−
C. glabra (Mill) Spach	+	+	−	−	+	+	+
C. cordiformis (Wang) K. Koch	+	+	+	−	−	−	−
Corylus americana Walt	+	−	−	+	−	+	−

* Explanation of symbols: + Present; − Absent; ! Marked abundance; (+) Secondary.

TABLE 2—*Continued*

NAME OF PLANT	HAGERSTOWN	MANOR VALLEY	CONOWINGO	CHESTER	MANOR	DEKALB	MANOR STONY
Ostrya virginiana (Mill) K. Koch	−	+	(+)	−	−	−	−
Betula lenta L.	−	−	−	−	+	+	(+)
Alnus rugosa (DuRoi) Spreng	(+)	+	(+)	+	+	+	−
Fagua grandifolia Ehrh	+	+	(+)	+	+	+	(+)
Castanea dentata Borkh	−	−	(+)	+	+	+	!
Quercus alba L.	+	+	(+)	+	+	+	−
Q. stellata Wang	−	−	+	+	−	+	−
Q. prinus L.	−	(+)	−	−	−	+	!
Quercus rubra L.	+	+	−	+	+	−	−
Q. palustris Muench	−	−	−	+	−	−	−
Q. coccinea Muench	+	−	+	+	+	+	(+)
Q. velutina Lam	+	+	+	+	+	+	+
Q. illicifolia Wang	−	−	+	−	−	+	−
Ulmus fulva Michx	+	+	−	+	(+)	−	−
U. americana L.	+	+	−	−	+	±	−
U. racemosa Thomas	−	−	−	−	+	−	−
Celtis occidentalis L.	!	−	−	−	(+)	−	−
Broussonetia papyrifera (L) Vent	+	+	−	+	−	−	−
Asarum canadense L.	+	−	−	−	−	−	−
Cerastium oblongifolium Torr	−	−	!	−	−	−	−
Claytonia virginica L.	+	+	−	+	+	+	−
Anemonella thalictroides Spach	+	+	−	+	+	(+)	−
Anemone riparia Fernald	−	+	−	+	−	(+)	−
Hepatica triloba Chaix	+	(+)	−	+	+	+	−
Aqilegia canadensis L.	!	−	−	−	−	−	−
Lirodendron tulipifera L.	!	+	−	+	+	+	−
Podophyllum peltatum L.	+	+	−	+	+	(+)	−
Sassafras variifolium (Salis.) Ftze	+	+	(+)	+	+	+	(+)
Benzoin aestivale (L) Nees	+	+	(+)	+	+	+	−
Sanguinaria canadensis L.	+	+	−	+	+	(+)	−
Cheilodonium majus L.	!	(+)	−	−	+	−	−
Dicentra cucullara (L) Bernh	+	−	−	+	−	−	−
Dentaria diphylla Michx	+	+	−	+	−	−	−
Sedum telephoides Michx	−	−	−	−	−	+	−
Saxifraga virginensis Michx	+	±	+	+	+	+	−
Heuchera americana L.	+	±	(+)	+	+	+	−
Mitella diphylla L.	+	−	−	−	−	−	−
Hamamelis virginiana L.	+	+	−	+	(+)	+	−
Platanus occidentalis L.	!	−	−	+	+	−	−
Gillenia trifolia (L) Moench	−	−	−	−	+	−	−
Amelanchier canadensis L.	−	+	−	+	+	!	−
A. oblongifolia Roem	−	−	−	−	−	+	−
Prunus virginiana L.	+	+	(+)	+	+	+	(+)

TABLE 2—*Continued*

NAME OF PLANT	HAGERSTOWN	MANOR VALLEY	CONOWINGO	CHESTER	MANOR	DEKALB	MANOR STONY
P. pennsylvanica L.	+	+	(+)	+	+	+	−
P. americana Marsh.	−	−	(+)	+	+	+	−
Gleditsia tricanthos L.	+	−	−	−	−	+	−
Cassia marilandica L.	+	−	−	+	−	+	−
C. nyctitans L.	−	−	−	−	(+)	−	+
Bartisia tinctoria (L) R. Br.	−	−	(+)	−	−	+	+
Robinia pseudo-Accacia L.	+	(+)	−	+	!	+	−
Geranium maculatum L.	+	+	−	+	+	+	−
Ailanthus glandulosa Desf.	+	+	−	+	+	+	(+)
Rhus typhina L.	−	+	−	+	+	+	−
R. glabra L.	+	+	(+)	+	+	+	−
R. copallina L.	−	−	−	−	+	+	−
R. toxicodendron L.	+	+	+	+	+	+	+
Euonymus americanus L.	−	−	−	−	+	−	−
E. obovatus Nutt.	−	+	−	−	(+)	−	−
Celastrus scandens L.	+	−	−	−	+	−	−
Staphylea trifolia L.	+	−	−	−	−	−	−
Acer rubrum L.	+	+	+	+	+	+	(+)
A. Negundo L.	+	−	−	+	+	−	−
Psedra quinquefolia (L) Greene	+	+	+	+	+	+	−
Vitis cordifolia Michx.	+	+	−	+	+	+	−
Hypericium gentianoides (L) BSP.	−	−	−	−	−	+	+
Viola fimbriatula Sm.	−	−	+	−	(+)	+	−
V. pubescens Ait.	(+)	−	−	−	−	(+)	+
V. scabriuscula Schwein.	+	+	−	+	+	−	−
Aralia nudicaulis L.	−	−	−	−	+	+	−
Osmorhiza longistylis DC.	+	+	−	+	+	−	−
Cornus florida L.	+	+	(+)	+	+	+	(+)
Nyssa sylvatica Marsh	+	+	(+)	+	(+)	+	−
Chimaphila maculata (L) Pursh.	−	−	−	+	+	+	−
Pyrola americana Sweet	−	+	(+)	−	−	+	−
Kalmia latifolia L.	−	−	−	−	(+)	+	−
K. angustifolia L.	−	−	−	−	−	+	−
Epigea repens L.	−	−	−	+	+	+	!
Rhododendron nudiflorum Torr.	−	(+)	(+)	+	!	!	(+)
Gaylussacia baccata C. Koch	−	−	−	(+)	+	+	+
Vaccinium corymbosum L.	−	(+)	(+)	+	+	+	−
Lysimachia quadrifolia L.	−	−	−	+	+	+	(+)
Trientalis americana Pursh.	−	(+)	−	−	−	−	−
Fraxinus americana L.	+	+	−	+	+	+	−
F. pennsylvanica Marsh	+	+	−	−	+	−	−
var. *lanceolata* (Borkh) Sarg	−	(+)	−	−	−	−	−
F. nigra Marsh	+	−	−	+	+	−	−

TABLE 2—*Concluded*

NAME OF PLANT	HAGERSTOWN	MANOR VALLEY	CONOWINGO	CHESTER	MANOR	DEKALB	MANOR STONY
Asclepias tuberosa L.	−	−	−	−	+	+	−
Phlox sublata L.	−	−	+	−	−	−	−
Monarda fistulosa L.	+	−	−	−	+	−	−
Pycnanthemum torrei Benth.	+	−	(+)	−	+	+	−
Cunila originoides (L) Britton	−	−	−	−	+	+	−
Collinsonia canadensis L.	+	!	−	+	−	(+)	−
Paulownia tomentosa (Thunb) Steud.	+	+	−	−	−	−	−
Veronica officinalis L.	+	−	+	+	+	+	(+)
Melampyrum lineare Lam.	−	−	−	−	+	+	(+)
Plantago virginica L.	+	−	−	+	+	!	−
Mitchella repens L.	−	+	(+)	+	+	(+)	−
Symphorocarpus vulgaris Michx.	+	−	−	−	−	!	−
Viburnum acerifolium L.	+	+	−	+	+	+	−
Sambucus canadensis L.	+	+	−	+	(+)	+	−
Specularia perfoliata (L) DC	+	−	−	+	−	+	−
Campanula rotundifolia L.	+	−	−	−	+	+	−
Lobelia cardinalis L.	−	−	−	+	−	+	−
L. Kalmii	+	(+)	−	+	+	+	−
Solidago caesia L.	+	+	(+)	+	!	+	(+)
S. bicolor L.	+	(+)	(+)	+	+	+	+
S. puberula Nutt.	+	−	+	+	+	+	+
S. altissima L.	+	−	(+)	+	+	+	−
S. polycephala Fernald	−	−	+	−	+	−	−
Aster divaricatus L.	−	+	−	+	(+)	+	−
A. cordifolius L.	+	+	+	+	+	+	−
A. ericoides L.	−	−	+	+	!	+	(+)
A. depauperatus Fernald	−	−	!	−	−	−	−
A. multiflorus Ait.	+	+	+	+	+	+	−
A. dumosus L.	+	+	(+)	+	+	−	−
Seriocarpus asteroides (L) BSP	−	−	(+)	−	(+)	+	!

Compare the oaks: White oak (*Quercus alba*) is typical of rich neutral soil such as Hagerstown and Chester loams so that their abundant presence at once gives an index of soil conditions at that place. Post oak (*Quercus stellata*) is characteristic of the Barrens which, though neutral are poor because of the high magnesium content. Chestnut oak (*Quercus prinus*) is the dominant tree of acid soil, the Manor stony loam of the hills, where it is stunted by strong winds, or swampy acid portions of ravines where it can grow to large size.

Much has been written on the causes of soil acidity and many influences affecting it have been noted, soil physicists recognizing the effect of free mineral, or organic acids, colloidal material, absorption and adsorption phenomena. Effect of arrested leaf decay has been shown clearly by Coville (6) to give an alkaline soil when well-rotted but an acid soil when partially

decayed. Other factors influencing soil acidity depend upon physiographic features. Each soil type exhibits a general average acidity but the actual pH value varies with every variation of slope exposure, as has been well shown by Harshberger (10) at Guelph, Pa. Similar relations hold good in most of the ravines of the South Valley Hills where exposed dry slopes have a partially decayed leaf litter and a chestnut oak-ericaceous flora while the less exposed slopes have a well-rotted topsoil and a mesophytic flora. Degree of slope is likewise important. An admirable illustration was found among the Valley Forge Hills where Mt. Joy exhibited on the west face a gradual decrease in pH value from 7 to 5.5 in ascent with a change from a mesophytic flora to a sparse ericoid type. Relative elevation also plays a part. Depression of an area of a neutral soil type below level of ground water results in an acid soil. Examples of this were especially marked in the serpentine belt south of Paoli, where post oak and cedar gave place to chestnut and Vaccineae in swampy areas.

The physiological effect of soil acid on a plant is two fold as noted by Truog (21), indirect, as through fertility, and direct, as affecting availability of calcium.

It is suggested that the foregoing influences may aid in the development of plant varieties, and that some plants now listed as distinct may have gained their distinctive structure because of them. Thus *Viola scabriuscula* grows in rich damp neutral soil while *V. pubescens* grows in dry exposed acid soil, but on ascending an exposed hill-slope one finds intergradations of varying degrees of pubescence and of intermediate habit. However, on the lenticular knolls in the Valley where slate and limestone are interbedded *V. scabriuscula* was found growing high on the slope in pockets of limestone soil.

SUMMARY

From classic times it has been known that certain plants are indicative of conditions of the soil in which they grow. Many of the relations existing between soil and flora have been discovered but comparatively little work has been done in correlating plants with soil types. Some of these relations were investigated by the writer and a preliminary report is here given.

In soil testing the colorimetric method was used as being the most practical for field tests. Carbon dioxide of the soil solution was not found to affect the pH value in the tests.

The acidity of a soil type is a variable quantity but an average pH value may be assigned to each type. Those given represent surface conditions; borings are being made to determine subsoil acidity. Soil acid is governed in part by such factors as arrested leaf decay, and physiographic features of slope, degree of slope and relative elevation. Some types of soil seem to have an higher degree of acidity in late summer.

Soil acidity influences flora to such an extent that certain plants may be assigned as indicators, a number being listed for each type. Soil acidity perhaps induces variation in plant species.

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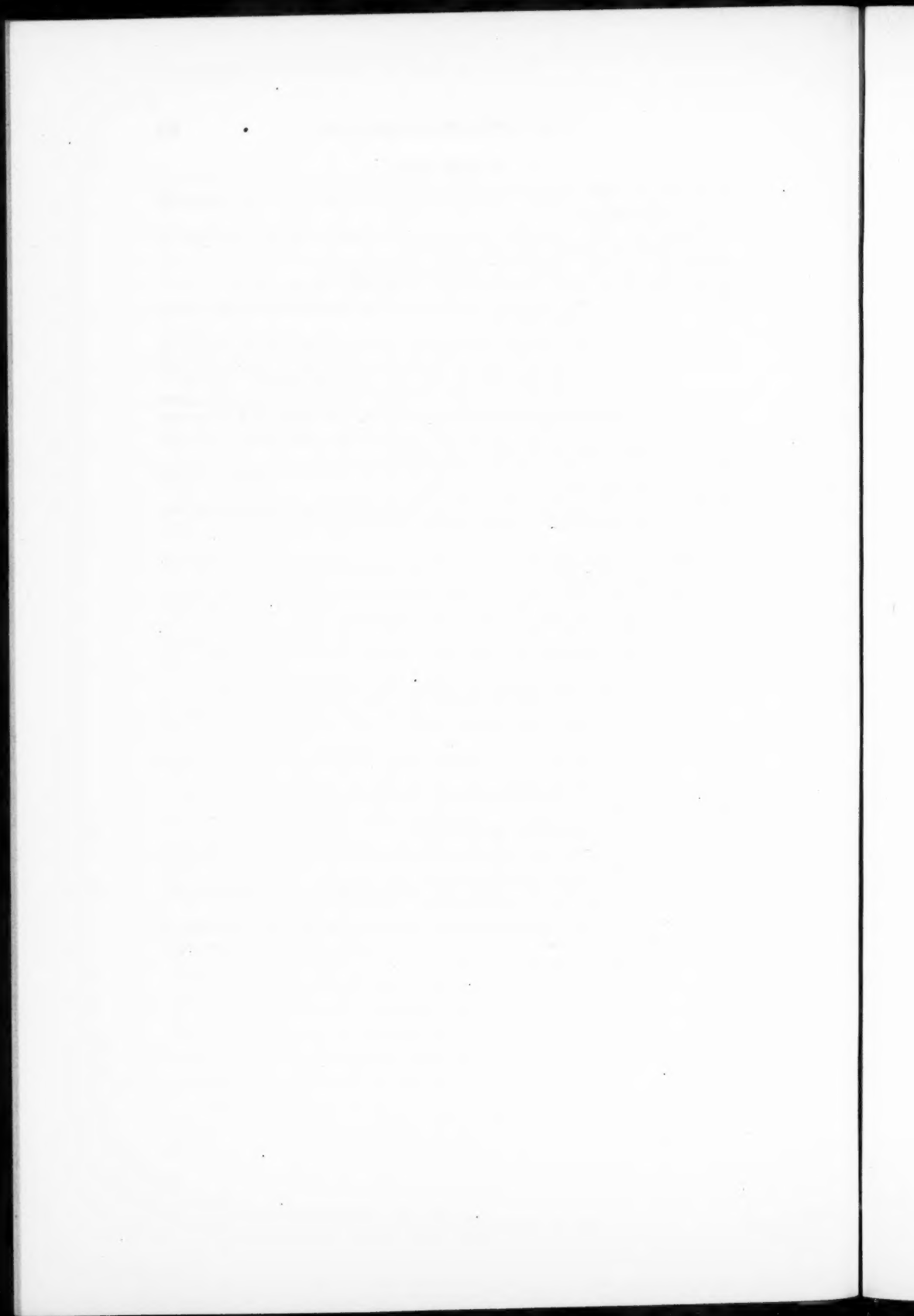
THE LATERITE SOILS OF FORMOSA ISLAND

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INTRODUCTION

There are in Formosa three kinds of rock which, after disintegration, form red colored soils. These are basalt, andesite and sedimentary rocks. Among these, the last mentioned is the most common as a mother rock of red soils. The soils belonging to this class occupy about 14 per cent of Formosa's cultivated area, *i.e.*, 265,000 acres. This area is located principally in the northern part of the island, and diminishes gradually toward the south except at the southern extremity. It occurs as more or less elevated land or terraces. The red colored soil always covers gravel layers which sometimes extend to a depth of several hundred feet. The gravels are roundish in shape and the red colored soil fills in between them. The soil and gravel seem to be of the same origin from a geological standpoint. Many gravels are red in color, as well as the soil surrounding them, and are, no doubt, derived from sandstones and shales. It seems, therefore, that the red colored soil is derived from the Tertiary sandstones and shales. Furthermore it is from diluvial and not from aeolian or volcanic formation, as suggested by some geologists who have visited the island. The characterisitc color of this soil is deep brick-red or brown, the color being darkened when it is moistened. Its texture is that of very heavy clay and it forms easily in lumps. When a field drys up after a rain, it becomes so hard that plowing is impossible.

The native people who live on the plateaus use this soil as a clarifying medium for their home supply of water. There are no streams and it is very difficult to get well water, hence contaminated and turbid water must be sufficiently purified for home use. To accomplish this they mix the contaminated water of a pond with soil in a barrel, stir it up and allow it to settle. In a few hours the water settles clear enough for home use. It stands to reason that colloidal substances in the soil withdraw suspended materials even including undesirable microörganisms. Stirring aids aggregation and flocculation of colloidal materials under certain circumstances.

Oxides, hydrates and some silicates of iron and aluminum represent the colloidal materials in the soil. These are found adhering to each other or coated on quartz sands. Ordinarily the alkali and alkali earth content is very low, on

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account of leaching out by long weathering. Quartz, however, remains in large proportion in the soil. Humus and other organic substances are present in small quantity, since climatic conditions rarely permit their accumulation. This soil (1, 2, 3) together with two other red colored soils may in a broad sense be classified as "laterite." Originally the name laterite was applied to a red residual soil which was found in India. But the laterite is defined as a vesicular, highly ferruginous, brick-red clay soil occurring in the tropical and subtropical regions. It is derived from various rocks which are extremely disintegrated by weathering actions. The laterites in Formosa conform to this definition in that they possess such characteristics and mode of formation. A large part of the Oolong tea gardens and thousands of acres of rice fields occupy the laterite area of the Tertiary origin. Investigation looking to the improvement of fertility in the laterite soils is of greatest importance, inasmuch as its low productivity is a serious handicap in the Formosan agriculture.

Productivity of crops

The most important laterite in Formosa is a residual clay soil which originated from sandstones and shales. Consequently soluble ingredients in it have been leached out by continuous weathering actions. Various agencies of decomposition under the tropical conditions do not permit the accumulation of organic matter in the soil. On this account, chemical and physical properties of the soil are unfavorable to production of most crops. Brief note of the productivity with respect to certain crops may be of interest in connection with the laterite soil.

Tea

Among crops, the tea plant, a perennial shrub, is the most adaptable and common in the laterite area. Remarkable Oolong tea of good quality is produced on this soil. But an average production of dried tea leaves per annum is about 300 pounds per acre, which is 60 per cent of a good average tea yield.

Rice

At the foot of hills or in lower places of the laterite region which are irrigable, rice fields are quite extensive. The soil texture is very heavy and the subsoil quite impervious, therefore percolation of water through the soil is very difficult. As a result some plots are irrigated only with the natural rainfall. The general fertility is very poor and production of rice corresponds to about 50 per cent of a normal crop.

Sugar cane

Lands not suitable for tea plantation and not in the irrigable parts of this soil are used for cultivation of sugar cane, sweet potato, sesame, peanut, etc. For the production of sugar cane these lands are hardly successful on account of the difficulty with which the plant roots penetrate the soil. The cane yield therefore is ordinarily about one-third of that expected in favorable regions.

It may be said of other crops that, in general, yields are from 35 to 60 per cent of the normal. No crops grow as luxuriantly in the laterite soil as on other fertile lands. Farmers who cultivate these areas at all find it necessary to pay special attention to soil management and maintenance of its fertility.

CHEMICAL COMPOSITION

Many samples of laterite which are derived from the Tertiary rocks have been analyzed in the Government Soil Survey of Formosa. Table 1 gives the composition of five representative soils from different parts of the island.

TABLE 1

Chemical composition of five Formosan laterites

CONSTITUENTS	YOBAIREKI	SONAMPI	TAISHO NANTO	MT. TAKAO	ROPII
	per cent	*per cent*	*per cent*	*per cent*	*per cent*
Alumina, Al_2O_3	15.89	9.74	11.24	24.55	11.91
Ferric oxide, Fe_2O_3	4.36	3.46	3.85	8.39	6.83
*Ferrous oxide, FeO	1.76	1.44	1.47	2.13	2.25
Manganese oxide, Mn_3O_4	0.16	0.19	0.30	0.26	0.21
Lime, CaO........................	0.16	0.11	0.17	0.51	0.31
Magnesia, MgO	0.30	0.25	0.32	0.47	0.38
Potassium oxide, K_2O	0.29	0.19	0.17	0.41	0.19
Sodium oxide, Na_2O	0.27	0.84	0.33	0.61	0.20
Silica, SiO_2........................	71.48	72.67	76.80	57.99	73.59
Phosphorus pentoxide, P_2O_5	0.09	0.07	0.13	0.44	0.19
Sulfur trioxide, SO_3	0.03	0.09	0.09	0.34	0.20
Chlorine, Cl......................	0.01	0.002	0.01	0.002	0.005
Loss on ignition	6.34	10.85	4.83	6.08	4.03
Total........................	101.14	99.902	99.71	102.182	100.495
Nitrogen........................	0.12	0.06	0.12	0.16	0.14

*Includes titanium oxide, TiO_2.

It is noticeable that these soils show a composition quite different from Indian laterite (2), especially in that they contain a large amount of silica and relatively low quantity of alumina and iron oxide. The quantity of alkalies and alkaline earths in the Formosan laterite is particularly small and this is true also of the acidic elements such as phosphorous and sulfur. These facts all indicate that the soil is a residual product of rocks which were disin-

tegrated by the tropical conditions. It is recognized that no one is able to
estimate exactly the degree of soil fertility by the results of chemical analyses.
Such results, however, will very often aid in directing one's judgement regard-
ing fertility. Table 1 shows that the soils mentioned are very low in plant
nutrients with the exception of no. 4, the laterite of Mt. Takao. The defi-
ciency is especially marked in the phosphoric acid and nitrogen contents of the
soils described. It is supposed that aluminum and iron occur in the form of
oxides, hydrates and silicates and that these elements function principally
through their colloidal nature.

SEPARATION OF COLLOIDAL MATERIALS AND THEIR CHEMICAL COMPOSITION (4)

A certain amount of laterite was treated with a large quantity of distilled
water, strongly agitated, and the colloidal solution separated by a Sharples
centrifuge. The centrifuge bowl running at a speed of 40,000 revolutions per
minute served to separate the colloidal solution from the larger soil grains.
The colloidal solution was then filtered through Pasteur-Chamberland filters
and the colloidal substances remaining on the filters collected for study. The
colloidal solution which is characterized by its marked Brownian movement
observed under the ultra-microscope, was dried and its chemical composition
determined for comparison with the soil from which it was derived.

TABLE 2

Chemical composition of colloidal materials in the laterite in comparison with the original soil

CONSTITUENTS	COLLOIDAL MATERIALS	ORIGINAL SOIL
	per cent	*per cent*
Alumina, Al_2O_3	31.19	12.79
Iron oxide, Fe_2O_3	13.77	4.94
Titanium oxide, TiO_2	0.70	1.25
Manganese oxide, Mn_3O_4	0.10	0.05
Lime, CaO	0.25	0.21
Magnesia, MgO	0.99	0.38
Potassium oxide, K_2O	0.17	0.11
Sodium oxide, Na_2O	0.16	0.11
Silica, SiO_2	35.79	73.50
Phosphorus pentoxide, P_2O_5	0.41	0.24
Sulfur trioxide, SO_3	0.31	0.17
Loss on ignition	15.54	6.31
Total	99.38	100.06
Nitrogen	0.18	0.12

It is not to be doubted that colloidal substances of this soil consist mainly
of aluminum and iron compounds which are assumed to be oxides, hydrates
and silicates. The large amount of loss on ignition in colloidal substances sup-

ports an assumption of the presence of hydrates and hydrous silicates. Decrease of silica in the colloid indicates that the majority of quartz grains was transmitted to the solid portion. Titanium compounds were lower in the colloid, perhaps on account of their stability against disintegration.

PETROGRAPHIC EXAMINATION (5, 6)

This soil obviously contains traces of various soluble salts which, however, are not detectable unless concentrated. A preliminary petrographic examination was carried on with insoluble soil particles. For an easier observation a small quantity of the soil was washed with distilled water and the soluble as well as colloidal materials permitted to run off. The residual dried sandy portion was identified under a petrographic microscope by the standard methods. An examination showed the following minerals present:

> Quartz, SiO_2
> Amorphous silica, SiO_2
> Hematite, Fe_2O_3
> Magnetite, Fe_3O_4
> Tourmaline, boro-silicate of Al, Fe, and alkali metals
> Zircon, $ZrSiO_4$
> Chlorite, a silicate of iron, aluminum and magnesium
> Bauxite, $AlFe(OH)_3$
> Hornblende, silicates of Al, Fe, Mg, Ca, Na

Among the minerals, quartz grains are the most abundant. Amorphous silica, hematite, magnetite and tourmaline in lesser quantity comprise the principal mineral ingredients of the soil. Zircon frequently comes into the optical field, but other minerals are very rare. There are, however, perhaps traces of several minerals which escaped identification. The detection of certain mineral grains serves further to confirm our judgement of the fertility of a soil.

RELATION BETWEEN COLOR OF LATERITE AND ITS IRON CONTENT

Laterite is characterized by its deep red color, owing to high iron content. In fact the name laterite originates from a Latin word, *later* which means brick. The color of Formosan laterites ranges from yellow or brown to red or deep-brown red. A series of laterite samples which have different colors from light to dark, were analyzed and compared as to the amount of iron present. Results of the analyses are given in table 3.

As is shown in table 3, the color of soils is not dependent to any considerable degree upon the iron content. It depends rather upon the degree of oxidation and distribution of iron compounds over soil grains. The finer distribution of the oxide usually indicates the deeper color, because much of ferruginous compounds form coatings on soil grains.

TABLE 3

Relation between color of laterite and its iron content

LOCATION	SOIL	COLOR	IRON OXIDE
			per cent
Boko Islets............	Basaltic laterite	Brownish red	20.70
	Basaltic laterite	Deep brown	19.99
	Basaltic laterite	Reddish brown	12.08
Taichu...............	Tertiary laterite	Brown	3.33
	Tertiary laterite	Light brown	2.08
Boko Islets............	Basaltic clay soil	Light brown	18.52
	Basaltic clay soil	Dark grey	15.02
Nanto.................	Tertiary loam	Grey	2.59
Mt. Ari...............	Tertiary clay soil	Yellow	8.00

SUMMARY

1. There is a kind of laterite which is derived from the Tertiary rocks in Formosa. It is not the same as Indian laterite, but belongs to the laterite class in a broad sense.

2. This soil covers the diluvial formation in the island and usually forms hills or plateaus.

3. It contains oxides, hydrates and silicates of aluminum and iron. These have their principal function by virtue of their colloidal nature in the soil.

4. The fertility of this soil is very poor, especially in nitrogenous and phosphatic nutrients.

5. By detection under a petrographic microscope quartz, amorphous silica, hematite, magnetite, tourmaline, zircon, etc., were identified.

6. The characteristic deep red color of this soil depends in general upon the iron oxide content and particularly upon the distribution of this upon the soil grains.

This paper is a brief note on investigation of Formosan laterite. There are many other data already available and under investigation. These will be reported in later papers.

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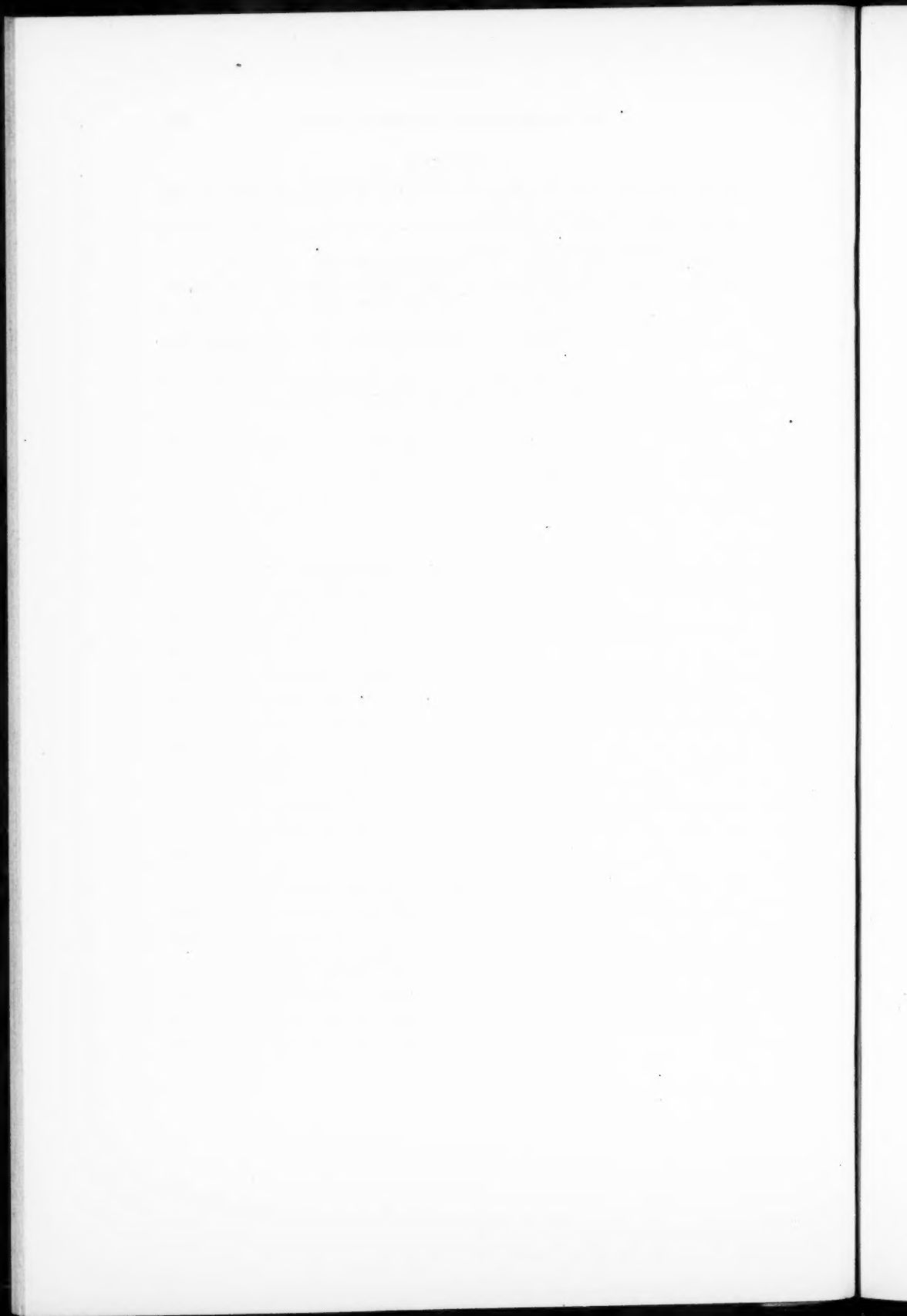
FURTHER STUDIES ON THE SOLUBLE SALT CONTENT OF FIELD SOILS

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In a previous publication (1) data from a limited study of the soluble salt content of soils in the field were presented and the following observations made.

1. When soils were maintained free from vegetation there was a continual variation of the soluble salt content of the stratum $\frac{1}{4}$ to 6 inch. Early in the spring the concentration was quite low but increased to a maximum in the summer and then decreased again.

2. While there were slight variations of the salt content of the subsoil 6 to 12-inch section, there was no tendency to reach a maximum and recede.

3. When no vegetation was present a considerable concentration of salts was noted in the surface $\frac{1}{4}$-inch of soil during periods of drought.

4. When the soil supported a growth of vegetation the tendency for the salts to accumulate at the surface was largely prevented.

5. Crop growth tended to decrease the amount of soluble material in the $\frac{1}{4}$ to 6 inch section and to a less extent in the 6 to 12-inch section. The nature of the crop seemed to have some bearing on this action.

These field studies have been continued and the scope of the experiments enlarged to include several other phases of the problem. The purpose of this publication is to present the data obtained during the years 1919 and 1920.

COLLECTION OF SAMPLES

In collecting the samples during 1919 three depths were considered. The surface soil to a depth of approximately $\frac{1}{4}$ inch was scraped off with a spatula. The next sample was taken to a depth of 6 inches and was called the $\frac{1}{4}$ to 6 inch section. The third sample represented the 6 to 12-inch stratum. Every precaution was taken to prevent the contamination of any sample by soil from another section. The samples were taken immediately to the laboratory, air dried and passed through a two millimeter screen. Samples were collected every month from March to Ocotber, inclusive, from areas maintained free of vegetation by scraping with a hoe and adjacent areas bearing sod or growing crops.

METHOD OF PROCEDURE

The concentration of the soil solution was measured by means of the Beckmann thermometer. The samples were prepared by adding sufficient water to a 20-gm. sample in a freezing tube to thoroughly saturate the soil and upon standing form a column approximately 1/16 inch deep on the surface. The proper amount of water for each soil was carefully determined at the beginning of the experiment and the same amount used in each succeeding determination on the samples. It was believed that by this procedure more accurate measurements of small variations could be obtained than by the common method of adding a uniform volume of water to each soil regardless of texture. The data presented represent the average of two or more closely agreeing determinations.

EXPERIMENTAL

The data from the plots maintained free of vegetation will be considered first. The concentration of the soil solution of the $\frac{1}{4}$ to 6 inch section, as represented by the freezing point depression, for the year 1919 are given in table 1.

These data show that early in the spring the amount of soluble material in this section of the soils was very limited. Later, during the summer months, the concentration of the soil solution increased in most of the soils, but decreased again in the late summer or fall. The variations in concentration were not so regular in the case of the virgin soils as they were for the field soils. The data as a whole, however, are in accord with those previously reported with the exception that in 1918 the maximum concentration was reached in June or July, while in 1919 this did not occur until somewhat later.

The data for the 6 to 12-inch sections are shown in table 2.

The concentration of the soil solution in the 6 to 12-inch stratum or so-called subsoil showed slight variations from month to month but no tendency to attain a maximum. These data are also in accord with the observations of 1918.

The data for the $\frac{1}{4}$-inch section show much more variation and offer an opportunity for interesting study. The results are included in table 3.

The data for the $\frac{1}{4}$-inch sections are very interesting inasmuch as they show a great variation in concentration from month to month. As noted in 1918 there is a strong tendency for an accumulation of soluble material to occur in this layer especially during periods of light or no rainfall. This material may be drawn from the lower sections by water movements. Rainfall undoubtedly affects these accumulations at the surface, light showers followed by high temperatures possibly permit further movements to the surface at the expense of the layer of soil immediately beneath, while heavy rains may result in a carrying of the soluble material to a considerable depth. Some data on this point have been presented (earlier publications) by McCool and Millar (1) and by Bouyoucos and McCool (2). This phase of the study will receive

TABLE 1

Soluble material in the ¼ to 6–inch section of soils free of vegetation, expressed in terms of freezing point depression

SOIL TYPE	MARCH 24	APRIL 26	MAY 28	JUNE 30	JULY 26	AUGUST 23	SEPTEMBER 26	OCTOBER 24
Virgin soil								
	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.
Coloma loamy sand	0.008	0.010	0.007	0.003	0.007	0.003	0.001	0.001
Miami sandy loam	0.004	0.008	0.007	0.007	0.004	0.022	0.007	0.009
Clyde sandy loam	0.014	0.010	0.009	0.010	0.009	0.009	0.008	0.011
Miami sandy loam (light phase)		0.006	0.004	0.003	0.016	0.002		
Miami very fine sandy loam		0.001	0.002	0.005	0.008	0.008	0.008	0.008
Miami silt loam	0.010	0.008	0.009	0.008	0.021	0.017	0.005	0.012
Miami silt loam, no. 2	0.004	0.012	0.005	0.004	0.002	0.004	0.005	0.002
Field soils								
Coloma loamy sand	0.005	0.003	0.007	0.006		0.002	0.002	0.002
Miami sandy loam	0.007	0.012	0.002	0.007	0.018	0.011	0.011	0.003
Clyde sandy loam	0.005	0.005	0.006	0.006	0.006	0.032	0.028	0.003
Miami sandy loam (light phase)		0.008	0.007	0.002	0.009	0.008	0.000	0.006
Miami very fine sandy loam	0.009	0.008	0.006	0.006	0.011	0.020	0.020	0.010
Miami silt loam	0.009	0.005	0.004	0.009	0.016	0.008	0.008	0.001
Miami silt loam no. 2	0.008	0.007	0.003	0.006	0.017	0.002	0.007	0.012

TABLE 2

Soluble material in the 6 to 12-inch section of soils free of vegetation, expressed in terms of freezing point depression

SOIL TYPE	MARCH 24	APRIL 26	MAY 28	JUNE 30	JULY 26	AUGUST 23	SEPTEMBER 26	OCTOBER 24
Virgin soil								
	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.
Coloma loamy sand	0.008	0.009	0.000	0.003	0.003	0.001	0.001	0.010
Miami sandy loam	0.007	0.000	0.004	0.010	0.002	0.002	0.008	0.005
Clyde sandy loam	0.011	0.006	0.001	0.010	0.005	0.002	0.008	0.002
Miami sandy loam (light phase)		0.007	0.001	0.002	0.003	0.002		
Miami very fine sandy loam	0.010	0.001	0.002		0.005	0.001	0.001	0.002
Miami silt loam	0.011	0.002	0.004	0.005		0.010	0.008	0.005
Miami silt loam, no. 2	0.002	0.004	0.001	0.002	0.010	0.001	0.002	0.003
Field soil								
Coloma loamy sand	0.006	0.002	0.003	0.003	0.009	0.001	0.001	0.001
Miami sandy loam	0.009	0.001	0.004	0.008	0.003	0.009	0.006	0.001
Clyde sandy loam	0.009	0.005	0.000	0.002	0.003	0.006	0.004	0.003
Miami sandy loam (light phase)		0.002	0.001	0.002	0.003	0.002	0.000	0.002
Miami very fine sandy loam	0.010	0.006	0.000	0.003	0.006	0.002	0.008	
Miami silt loam	0.012	0.000	0.004	0.002	0.003		0.002	0.001
Miami silt loam, no. 2	0.002	0.006	0.004	0.003	0.002	0.002	0.007	0.004

further consideration later in this paper. For reference, the daily precipitation for the period of sampling is given in table 4.

The influence of vegetation of various kinds on the accumulation of soluble material in various sections of the soil and the subsequent movements of these soluble substances was also studied. The data in table 5 from some of the soils studied are representative.

Vegetation exerts a marked effect upon the accumulation and movement of salts in the soil. A study of the data for 1919 presented in table 4 brings out the following points. When grass or any of the common crops are present the

TABLE 3

Soluble material in the ¼-inch section of soils free of vegetation, expressed in terms of freezing point depressions

SOIL TYPE	MARCH 24	APRIL 26	MAY 28	JUNE 30	JULY 26	AUGUST 23	SEPTEMBER 26	OCTOBER 24
Virgin soil								
	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.
Coloma loamy sand....................	0.006	0.016	0.020	0.032		0.010	0.018	0.009
Miami sandy loam.....................	0.003	0.018	0.032	0.040	0.012	0.066	0.030	0.030
Clyde sandy loam......................	0.008	0.020	0.032	0.029	0.008	0.018	0.028	0.011
Miami sandy loam (light phase)........		0.010	0.013	0.008	0.011	0.006		
Miami very fine sandy loam............	0.006	0.004	0.012	0.053	0.039	0.093	0.123	0.075
Miami silt loam.......................	0.010	0.024	0.055	0.037	0.061	0.145	0.101	0.192
Miami silt loam, no. 2.................	0.010	0.010	0.014	0.006	0.008	0.003	0.009	0.011
Field soil								
Coloma loamy sand....................	0.004	0.005	0.015	0.014	0.026	0.002	0.015	0.010
Miami sandy loam.....................	0.004	0.020	0.040	0.057	0.069	0.049	0.056	
Clyde sandy loam......................	0.004	0.023	0.055	0.058	0.068	0.060	0.101	0.071
Miami sandy loam (light phase)........	0.009	0.006	0.008	0.009	0.012	0.003	0.015	
Miami very fine sandy loam............	0.010	0.029	0.020		0.033	0.215	0.088	0.185
Miami silt loam.......................	0.013	0.013	0.017	0.018	0.022	0.041	0.030	0.021
Miami silt loam, no. 2.................	0.008	0.006	0.017	0.018	0.011	0.010	0.024	0.056

accumulation of salts at the surface is largely prevented. Also such vegetable growth influences the concentration of the soil solution in the ¼ to 6-inch section and to some extent in the 6 to 12-inch stratum. These results are in accord with the findings for the previous year.

It will be noted that in both 1918 and 1919 the samples from the ¼ to 6-inch section of the field soils free of vegetation tended to show a somewhat greater accumulation of salts than the corresponding samples from the fence rows. This seemed rather unusual, inasmuch as the latter soils contained more organic matter; a possible explanation being the more thorough mixing of the organic matter in the field soils. To throw some light on this question plots along the

fences were scraped free of grass and then thoroughly hoed to a depth of 6 inches in order to thoroughly incorporate the organic matter in the surface soil. The data are presented in table 6.

A consideration of the data shows a great variation in concentration of the soil solution from time to time, especially in the case of the $\frac{1}{4}$-inch section.

TABLE 4

Daily precipitation, 1919

DATE	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER
	inches	inches	inches	inches	inches	inches	inches	inches
1	T*		0.85					0.01
2								
3		0.16	1.46			T		
4	0.40		0.95			2.19	0.01	0.01
5	0.03	T		T	0.04	0.35		0.15
6	T	0.09		0.06				
7		0.70	T	0.27				
8	0.30	0.03	0.15					
9	1.11	0.26			0.05		T	0.07
10	0.01	0.28	T				0.21	0.45
11		T	T	0.21			0.01	
12		0.01		0.01	0.51			
13	T					T		
14		0.02	0.09		0.13	T	0.01	T
15	0.56	1.17	0.33	T		T		0.01
16	0.23	0.77	0.09	0.22		0.66		0.06
17	0.39	0.04	T			0.01		
18						0.07	0.01	
19		T	0.81				0.39	
20		0.04	0.12	0.05	0.06	0.02	0.43	0.03
21			0.01		0.06	0.08	0.54	0.01
22			0.19					0.01
23		0.34	0.05		T			
24		T		1.04				
25		T		0.46				0.13
26	0.08			0.05	0.30	0.04		0.15
27		0.11		T	0.20			0.23
28		0.11			0.11		0.02	0.02
29	0.19					0.58	0.69	0.13
30	0.18	T			0.17		0.29	0.72
31					0.06	0.03		0.81

*T = trace.

It is interesting to note, however, that there is no constant difference in favor of the soil maintained under any one of the conditions represented. This is true for every section of the soils studied and emphasizes the fact that there are many factors influencing the production and movement of soluble material in field soils.

TABLE 5

Effect of plant growth on the amount of soluble material in various soils during the season of 1919, expressed in terms of freezing point depressions

SOILS	MARCH 24	APRIL 26	MAY 28	JUNE 30	JULY 26	AUGUST 23	SEPTEMBER 26	OCTOBER 24
Coloma loamy sand	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.
Virgin soil free of vegetation								
¼ inch section	0.006	0.016	0.020	0.032		0.010	0.018	0.009
¼–6 inch section	0.008	0.010	0.007	0.003	0.007	0.003	0.001	0.001
6–12 inch section	0.008	0.009	0.001	0.003	0.003	0.001	0.001	0.010
Virgin soil under sod								
¼ inch section	0.012	0.011	0.006	0.003	0.010	0.009	0.002	0.051
¼–6 inch section	0.008	0.009	0.002	0.004	0.006	0.004	0.002	0.006
6–12 inch section	0.007	0.003	0.001	0.001	0.001	0.002	0.001	0.008
Field soil free of vegetation								
¼ inch section	0.004	0.005	0.015	0.014	0.026	0.002	0.015	0.010
¼–6 inch section	0.005	0.003	0.007	0.006		0.002	0.002	0.002
6–12 inch section	0.006	0.002	0.003	0.003	0.009	0.001	0.001	0.001
Field soil growing wheat								
¼ inch section	0.005	0.008	0.005	0.002	0.008	0.003	0.008	0.009
¼–6 inch section	0.011	0.003	0.001	0.006	0.004	0.001	0.003	0.001
6–12 inch section	0.009	0.007	0.004	0.002	0.009	0.001	0.001	0.001
Timothy followed by corn								
¼ inch section			0.003	0.042		0.003	0.050	0.031
¼–6 inch section			0.003	0.005		0.003	0.003	0.001
6–12 inch section			0.001	0.007		0.001	0.001	0.008
Miami sandy loam								
Virgin soil free of vegetation								
¼ inch section	0.003	0.018	0.032	0.040	0.012	0.066	0.030	0.030
¼–6 inch section	0.004	0.008	0.007	0.007	0.004	0.022	0.007	0.009
6–12 inch section	0.007	0.001	0.004	0.010	0.002	0.002	0.008	0.005
Virgin soil under sod								
¼ inch section	0.012	0.006	0.005	0.022	0.013	0.011	0.009	0.013
¼–6 inch section	0.006	0.007	0.003	0.002	0.005	0.004	0.003	0.005
6–12 inch section	0.003	0.003	0.004	0.003	0.003	0.001	0.003	0.001
Field soil free of vegetation								
¼ inch section	0.004	0.020	0.040	0.057	0.069	0.049	0.056	
¼–6 inch section	0.007	0.012	0.002	0.007	0.018	0.011	0.011	0.003
6–12 inch section	0.009	0.001	0.004	0.008	0.003	0.009	0.006	0.001
Field soil growing timothy followed by corn								
¼ inch section	0.005	0.002	0.009	0.002	0.011	0.009	0.005	0.003
¼–6 inch section	0.008	0.007	0.003	0.004	0.009	0.006	0.003	0.001
6–12 inch section	0.008	0.002	0.001	0.001	0.009	0.005	0.001	0.001
Field soil growing clover								
¼ inch section		0.010	0.010	0.001	0.009		0.002	0.009
¼–6 inch section		0.008	0.001	0.002	0.006		0.003	0.003
6–12 inch section		0.006	0.008	0.003	0.002		0.004	0.003

TABLE 5—*Continued*

SOILS	MARCH 24	APRIL 26	MAY 28	JUNE 30	JULY 26	AUGUST 23	SEPTEMBER 26	OCTOBER 24
	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.
Field soil growing oats								
¼ inch section			0.060	0.004	0.012	0.006	0.014	0.022
¼–6 inch section			0.004	0.003	0.011	0.004	0.010	0.001
6–12 inch section			0.008	0.002	0.005	0.007	0.003	0.005
Clyde sandy loam								
Virgin soil free of vegetation								
¼ inch section	0.008	0.020	0.032	0.029	0.008	0.018	0.028	0.011
¼–6 inch section	0.014	0.010	0.009	0.010	0.009	0.009	0.008	0.011
6–12 inch section	0.011	0.006	0.001	0.010	0.005	0.002	0.008	0.002
Virgin soil under sod								
¼ inch section	0.020	0.007	0.011	0.007	0.008	0.011	0.008	0.012
¼–6 inch section	0.010	0.010	0.005	0.008	0.006	0.006	0.009	0.003
6–12 inch section	0.013	0.005	0.008	0.008	0.003	0.002	0.003	0.002
Field soil free of vegetation								
¼ inch section	0.004	0.023	0.055	0.058	0.068	0.060	0.101	0.044
¼–6 inch section	0.005	0.005	0.006	0.006	0.006	0.032	0.028	0.003
6–12 inch section	0.009	0.005	0.001	0.002	0.003	0.006	0.004	0.003
Field soil growing wheat								
¼ inch section	0.004	0.005	0.009	0.009	0.013	0.018		0.020
¼–6 inch section	0.005	0.006	0.001	0.011	0.013	0.010		0.003
6–12 inch section	0.008	0.008	0.001	0.003	0.011	0.011		0.001
Miami very fine sandy loam								
Virgin soil free of vegetation								
¼ inch section	0.006	0.004	0.012	0.053	0.039	0.093	0.123	0.075
¼–6 inch section		0.001	0.002	0.005	0.008	0.008	0.008	0.008
6–12 inch section	0.010	0.001	0.001		0.005	0.001	0.001	0.001
Virgin soil under grass								
¼ inch section	0.018	0.006	0.009	0.004	0.020	0.008	0.012	0.033
¼–6 inch section	0.012	0.010	0.001	0.005	0.008	0.009	0.004	0.002
6–12 inch section	0.007	0.001	0.001	0.004	0.002	0.002	0.004	0.001
Field soil free of vegetation								
¼ inch section	0.010	0.029	0.020	0.186	0.033	0.215	0.088	0.185
¼–6 inch section	0.009	0.008	0.006	0.006	0.011	0.020	0.020	0.010
6–12 inch section	0.010	0.006	0.001	0.003	0.006	0.002	0.008	
Timothy and clover sod								
¼ inch section	0.010	0.007	0.009	0.004	0.018	0.023	0.020	0.012
¼–6 inch section	0.010	0.002	0.004	0.003	0.006	0.003	0.006	0.004
6–12 inch section	0.006	0.002	0.002	0.001	0.010	0.001	0.008	0.001
Miami silt loam								
Virgin soil free of vegetation								
¼ inch section	0.010	0.024	0.055	0.037	0.061	0.145	0.101	0.192
¼–6 inch section	0.010	0.008	0.009	0.008	0.021	0.017	0.005	0.012
6–12 inch section	0.011	0.002	0.004	0.005	0.028	0.010	0.008	0.005

TABLE 5—*Concluded*

SOILS	MARCH 24	APRIL 26	MAY 28	JUNE 30	JULY 26	AUGUST 23	SEPTEMBER 26	OCTOBER 24
	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.
Virgin soil under grass								
¼ inch section	0.018	0.008	0.009	0.004	0.010	0.008	0.009	0.010
¼–6 inch section	0.007	0.010	0.002	0.001	0.011	0.004	0.002	0.001
6–12 inch section	0.011	0.002	0.002	0.001	0.004	0.003	0.001	0.007
Field soil free of vegetation								
¼ inch section	0.013	0.013	0.017	0.018	0.022	0.041	0.030	0.021
¼–6 inch section	0.009	0.005	0.004	0.009	0.016	0.008	0.008	0.001
6–12 inch section	0.012	0.001	0.004	0.002	0.003		0.002	0.001
Field soil under alsike sod								
¼ inch section	0.015	0.010	0.030	0.001	0.014	0.010	0.020	0.007
¼–6 inch section	0.007	0.002	0.008	0.005	0.007	0.008	0.008	0.001
6–12 inch section	0.008	0.002	0.002	0.001	0.002	0.005	0.001	0.002
Field soil under corn								
¼ inch section			0.026	0.049	0.098	0.010	0.018	0.018
¼–6 inch section			0.007	0.008	0.028	0.007	0.019	0.011
6–12 inch section			0.010	0.006	0.002	0.003	0.002	0.002

TABLE 6

Comparison of amounts of soluble material in areas of virgin, virgin cultivated, and field soils free of vegetation, expressed in terms of freezing point depressions

SOIL AND DEPTH OF SAMPLE	APRIL 26	MAY 28	JUNE 30	JULY 26	AUGUST 23	SEPTEMBER 26	OCTOBER 24	AVERAGE
	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.
Coloma loamy sand								
Virgin soil								
¼ inch section	0.016	0.020	0.032		0.010	0.018	0.009	0.0174
¼–6 inch section	0.010	0.007	0.003	0.007	0.003	0.001	0.004	0.0050
6–12 inch section	0.009	0.000	0.003	0.003	0.001	0.001	0.010	0.0038
Virgin soil cultivated								
¼ inch section	0.012	0.035	0.016	0.017	0.002	0.010	0.010	0.0145
¼–6 inch section	0.011	0.004	0.006	0.003	0.002	0.002	0.001	0.0041
6–12 inch section	0.009	0.000	0.005	0.001	0.002	0.001	0.000	0.0025
Field soil								
¼ inch section	0.005	0.015	0.014	0.026	0.002	0.015	0.010	0.0124
¼–6 inch section	0.003	0.007	0.006	0.010	0.002	0.002	0.002	0.0044
6–12 inch section	0.002	0.003	0.003	0.009	0.001	0.001	0.000	0.0027
Miami sandy loam								
Virgin soil								
¼ inch section	0.018	0.032	0.040	0.012	0.066	0.030	0.030	0.0289
¼–6 inch section	0.008	0.007	0.007	0.004	0.022	0.007	0.009	0.0086
6–12 inch section	0.000	0.004	0.010	0.002	0.002	0.008	0.005	0.0047

TABLE 6—*Concluded*

SOIL AND DEPTH OF SAMPLE	APRIL 26	MAY 28	JUNE 30	JULY 26	AUGUST 23	SEPTEMBER 26	OCTOBER 24	AVERAGE
	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.
Virgin soil cultivated								
¼ inch section	0.010	0.030	0.051	0.035	0.040	0.032	0.022	0.0314
¼–6 inch section	0.009	0.004	0.014	0.015	0.016	0.021	0.013	0.0131
6–12 inch section	0.004	0.005	0.004	0.003	0.012	0.019	0.006	0.0076
Field soil								
¼ inch section	0.020	0.040	0.057	0.069	0.049	0.056		0.0485
¼–6 inch section	0.012	0.002	0.007	0.018	0.011	0.011	0.003	0.0091
6–12 inch section	0.001	0.004	0.008	0.003	0.009	0.006	0.001	0.0046
Clyde sandy loam								
Virgin soil								
¼ inch section	0.020	0.032	0.029	0.008	0.018	0.028	0.011	0.0209
¼–6 inch section	0.010	0.009	0.010	0.009	0.009	0.008	0.011	0.0094
6–12 inch section	0.006	0.001	0.010	0.005	0.002	0.008	0.002	0.0049
Virgin soil cultivated								
¼ inch section	0.020	0.024	0.014	0.013	0.021	0.021	0.021	0.0191
¼–6 inch section	0.012	0.011	0.012	0.016	0.013	0.012	0.002	0.0111
6–12 inch section	0.004	0.008	0.005	0.002	0.008	0.002	0.000	0.0041
Field soil								
¼ inch section	0.023	0.055	0.058	0.068	0.060	0.101	0.044	0.0584
¼–6 inch section	0.005	0.006	0.006	0.006	0.032	0.028	0.003	0.0123
6–12 inch section	0.005	0.000	0.002	0.003	0.006	0.004	0.003	0.0033
Miami silt loam								
Virgin soil								
¼ inch section	0.024	0.055	0.037	0.061	0.145	0.101	0.192	0.0878
¼–6 inch section	0.008	0.009	0.008	0.021	0.017	0.005	0.012	0.0114
6–12 inch section	0.002	0.004	0.005	0.028	0.010	0.008	0.005	0.0088
Virgin soil cultivated								
¼ inch section	0.004	0.066	0.053	0.038	0.072	0.024	0.071	0.0468
¼–6 inch section	0.005	0.012	0.016	0.024	0.020	0.019	0.011	0.0153
6–12 inch section	0.005	0.007	0.010	0.007	0.003	0.007	0.008	0.0067
Field soil								
¼ inch section	0.013	0.017	0.018	0.022	0.041	0.030	0.021	0.0231
¼–6 inch section	0.005	0.004	0.009	0.016	0.008	0.008	0.001	0.0073
6–12 inch section	0.000	0.004	0.002	0.003		0.002	0.001	0.0020
Miami very fine sandy loam								
Virgin soil								
¼ inch section	0.004	0.012	0.053	0.039	0.093	0.123	0.075	0.0570
¼–6 inch section	0.001	0.002	0.005	0.008	0.008	0.008	0.008	0.0057
6–12 inch section	0.000	0.000		0.005	0.001	0.000	0.000	0.0010
Virgin soil cultivated								
¼ inch section	0.007	0.012	0.035	0.016	0.032	0.019	0.040	0.0230
¼–6 inch section	0.010	0.008	0.008	0.004	0.003	0.007	0.005	0.0064
6–12 inch section	0.002	0.003	0.001	0.007	0.002	0.006	0.001	0.0031
Field soil								
¼ inch section	0.029	0.020	0.186	0.033	0.215	0.088	0.185	0.1080
¼–6 inch section	0.008	0.006	0.006	0.011	0.020	0.020	0.010	0.0116
6–12 inch section	0.006	0.000	0.003	0.006	0.002	0.008		0.0040

RESULTS FOR 1920

For the 1920 studies it was deemed advisable to change the depths of sampling somewhat in order to observe more closely the effects of rainfall on the salt content of the soil to approximately the depth of plowing. Accordingly the following soil strata were sampled 0 to $\frac{1}{4}$-inch; $\frac{1}{4}$ to 3-inch; 3 to 9-inch. The dates of sampling were also chosen with reference to climatic conditions instead of sampling monthly as was done previously. It was further found desirable to omit two of the soils previously included in these studies.

In studying the effect of rainfall on the accumulation of salts in the various soil strata and their movement from zone to zone it is only possible to consider the plots on the virgin soil maintained free of vegetation since those in the field were subject to various tillage operations. The data for these plots are presented in table 7 and the precipitation record covering the period of sampling is found in table 8.

A consideration of the data from the uncultivated plots shows that the moist weather preceding July 30 resulted in a decrease of the salt content of the $\frac{1}{4}$-inch stratum of three of the soils, the variation in the other being negligible. The results from the hoed plots are of no value for this date since these plots were given a thorough hoeing a few days before sampling and sufficient time had not elapsed for the distribution of salts to become adjusted.

The heavy precipitation preceding August 18 caused a further decrease in the accumulation of salts in the $\frac{1}{4}$-inch section of the soils, the Miami sandy loam varying somewhat from the other samples in this case. An increased movement of salts to the surface resulted from the dry period preceding October 5, with one exception, the hoed plot of Coloma loamy sand showing a decrease. This increase was in turn followed by a decrease in concentration of soluble material as a result of the rains shortly before December 3, the Miami silt loam being an exception.

The data for the $\frac{1}{4}$ to 3-inch sections show a considerable variation but a general tendency toward an increase of solubles for the October sampling. This would indicate a tendency for salts to move into this zone as a result of the dry weather preceding this date. For the 3 to 9-inch stratum an average of results shows an increase in freezing point depression on July 30 and October 5 with a decrease for August 18. It would appear, therefore, that the lighter rains preceding the July sampling had caused an increased production or movement of salts into this zone as had also the dry period preceding October 5; while the heavier rains during August had resulted in the washing of salts below this depth.

In considering these data it should be borne in mind that these plots are somewhat widely separated and that none of them lie within a mile of the rain gauge. In consequence there is opportunity for somewhat wide variations in the amount of precipitation received.

TABLE 7

Influence of rainfall on the distribution of soluble material in field soils, expressed in freezing point depressions

SOIL AND DEPTH OF SAMPLE	JULY 20	JULY 30	AUGUST 18	OCTO- BER 5	DECEM- BER 3
	°C.	°C.	°C.	°C.	°C.
Coloma loamy sand					
Uncultivated					
¼ inch section	0.012	0.013	0.006	0.015	0.010
¼–3 inch section	0.010	0.009	0.004	0.007	0.010
3–9 inch section	0.001	0.008	0.004	0.002	0.009
Previously hoed					
¼ inch section	0.006	0.060	0.034	0.016	0.010
¼–3 inch section	0.004	0.010	0.007	0.007	0.011
3–9 inch section	0.003	0.004	0.001	0.006	0.009
Miami sandy loam					
Uncultivated					
¼ inch section	0.040	0.020	0.030	0.081	
¼–3 inch section	0.006	0.011	0.012	0.030	
3–9 inch section	0.002	0.009	0.008	0.016	
Previously hoed					
¼ inch section	0.012	0.062	0.018	0.026	
¼–3 inch section	0.008	0.017	0.010	0.019	
3–9 inch section	0.001	0.008	0.011	0.016	
Clyde sandy loam					
Uncultivated					
¼ inch section	0.020	0.008	0.007	0.014	0.008
¼–3 inch section	0.009	0.004	0.004	0.008	0.006
3–9 inch section	0.004	0.002	0.002	0.004	0.008
Previously hoed					
¼ inch section	0.021	0.026	0.020	0.058	0.008
¼–3 inch section	0.009	0.002	0.010	0.021	0.008
3–9 inch section	0.004	0.010	0.006	0.011	0.008
Miami very fine sandy loam					
Uncultivated					
¼ inch section	0.024	0.018	0.014	0.020	0.010
¼–3 inch section	0.002	0.004	0.007	0.008	0.004
3–9 inch section	0.003	0.009	0.002	0.006	0.007
Previously hoed					
¼ inch section	0.030	0.018	0.013	0.015	0.008
¼–3 inch section	0.002	0.004	0.007	0.008	0.004
3–9 inch section	0.003	0.009	0.002	0.006	0.007
Miami silt loam					
*Uncultivated					
Previously hoed					
¼ inch section	0.027	0.024	0.004	0.018	0.018
¼–3 inch section	0.007	0.013	0.015	0.017	0.011
3–9 inch section	0.008	0.014	0.006	0.013	0.012

* This plot was accidentally destroyed.

The variation in the data also indicate that factors other than rainfall materially influence the distribution of the salts in field soils. It seems that texture, compaction and biological activities may also be important. A future paper will deal more in detail with this phase of the salt content of field soils.

TABLE 8

Daily precipitation, 1920

DATE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
	in.	*in.*	*in.*	*in.*	*in.*	*in.*
1	T*				0.35	0.70
2	0.05				0.21	T
3				0.02	0.01	
4						0.81
5	T	T	0.02			0.03
6	0.24	0.62			T	
7	T				0.02	
8	0.60				0.10	
9	0.03	0.24	0.05		0.09	0.06
10		T		0.01	T	0.16
11			T		T	0.01
12					T	
13	0.23	0.48			T	0.27
14	0.16				0.01	0.34
15			0.58	0.01	0.01	0.08
16		0.15		0.01	0.14	T
17						0.02
18	1.40				T	0.02
19						0.03
20			0.07	0.01		T
21	T	0.33			0.19	0.18
22					0.79	0.80
23	T				0.03	0.06
24	T		0.02	0.08	0.14	0.02
25				0.11	0.02	T
26		T	0.13	0.59	0.06	0.29
27		T	0.39	0.47	T	0.03
28	0.01					0.01
29	0.07	0.18	T	T	T	
30	0.14		T		0.07	0.01
31	0.08			0.06		0.01

* T = trace.

During the season of 1920 samples were not collected under as great a variety of crops as in previous years. The results of the freezing point determinations on the samples collected are given in table 9.

The tendency for vegetation to prevent the large accumulation of salts at the surface is again noticed in the data above. This substantiates the observations of the two previous years. It will be observed in some cases, however,

TABLE 9

Influence of vegetation on the accumulation and movement of salts in field soils, expressed in terms of freezing point depressions

TYPE AND CONDITION OF SOIL	JULY 30			AUGUST 18			OCTOBER 5			DECEMBER 3		
	½″ °C	½-3″ °C	3-9″ °C	½″ °C	½-3″ °C	3-9″ °C	½″ °C	½-3″ °C	3-9″ °C	½″ °C	½-3″ °C	3-9″ °C
Coloma loamy sand												
Virgin soil free of vegetation	0.013	0.009	0.008	0.006	0.004	0.004	0.015	0.007	0.002	0.010	0.010	0.009
Virgin sod	0.016	0.011	0.002	0.007	0.012	0.001	0.016	0.012	0.008	0.012	0.011	0.012
Field soil free of vegetation	0.011	0.005	0.005				0.005	0.004	0.001	0.010	0.008	0.010
Clover field	0.011	0.011	0.009	0.008	0.004	0.004	0.012	0.003	0.005	0.010	0.008	0.011
Miami sandy loam												
Virgin soil free of vegetation	0.020	0.011	0.009	0.030	0.012	0.008	0.081	0.030	0.016			
Virgin sod	0.010	0.005	0.001	0.010	0.005	0.002	0.018	0.010	0.007			
Field soil free of vegetation	0.170	0.019	0.011	0.008	0.002	0.015	0.037	0.018	0.018			
Timothy sod	0.008	0.005	0.005	0.003	0.003	0.001	0.019	0.016	0.014			
Corn following clover	0.070	0.005	0.012	0.007	0.003	0.012	0.018	0.008	0.017			
Oats	0.012	0.006	0.006	0.006	0.003	0.012	0.018	0.018	0.016			
Clyde sandy loam												
Virgin soil free of vegetation	0.008	0.004	0.002	0.007	0.004	0.002	0.014	0.008	0.004	0.008	0.006	0.008
Virgin sod	0.016	0.008	0.005	0.018	0.002	0.002	0.008	0.005	0.007	0.013	0.009	0.011
Field soil free of vegetation	0.018		0.007	0.014	0.005	0.002	0.025	0.008	0.004			
Clover	0.020	0.009	0.006	0.010	0.004	0.003	0.018	0.012	0.003			
Miami very fine sandy loam												
Virgin soil free of vegetation	0.018	0.004	0.009	0.014	0.007	0.002	0.020	0.008	0.006	0.010	0.004	0.007
Virgin sod	0.013	0.008	0.005	0.018	0.007	0.006	0.011	0.005	0.002	0.008	0.007	0.002
Field soil free of vegetation	0.007	0.005	0.010	0.017	0.008	0.007	0.006	0.003	0.005	0.008	0.008	0.008
Timothy sod	0.012	0.008	0.004	0.004	0.002	0.002	0.009	0.008	0.004	0.006	0.003	0.009
Miami silt loam												
*Virgin soil free of vegetation	0.018	0.008	0.006	0.019	0.005	0.004	0.016	0.008	0.009	0.017	0.012	0.007
Virgin sod	0.136	0.008	0.009	0.087	0.013	0.008	0.105	0.044	0.018			
Field soil free of vegetation	0.114	0.016	0.013	0.006	0.005		0.027	0.014	0.010	0.012	0.008	0.006
Corn after alsike sod	0.007	0.002	0.005	0.012	0.008	0.002	0.014	0.011	0.010			
Oats—stubble												

* This plot was accidentally destroyed.

TABLE 10

Comparative rate of formation of salts in cultivated and uncultivated soils free of vegetation, expressed in terms of freezing point depression

SOIL	JULY 20			JULY 30			AUGUST 18			OCTOBER 5			DECEMBER 3		
	½″	1-3″	3-9″	½″	1-3″	3-9″	½″	1-3″	3-9″	½″	1-3″	3-9″	½″	1-3″	3-9″
	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.
Coloma loamy sand															
Virgin scraped..........	0.012	0.010	0.001	0.013	0.009	0.008	0.006	0.004	0.004	0.015	0.007	0.002	0.010	0.010	0.009
Virgin hoed............	0.006	0.004	0.003	0.060	0.010	0.004	0.034	0.007	0.001	0.016	0.007	0.006	0.010	0.011	0.009
Miami sandy loam															
Virgin scraped..........	0.040	0.006	0.002	0.020	0.011	0.009	0.030	0.012	0.008	0.081	0.030	0.016			
Virgin hoed............	0.012	0.008	0.001	0.062	0.017	0.008	0.018	0.010	0.011	0.026	0.019	0.016			
Clyde sandy loam															
Virgin scraped..........	0.020	0.009	0.004	0.008	0.004	0.002	0.007	0.004	0.002	0.014	0.008	0.004	0.008	0.006	0.008
Virgin hoed............	0.021	0.009	0.004	0.026	0.002	0.010	0.020	0.010	0.006	0.058	0.021	0.011	0.008	0.008	0.008
Miami very fine sandy loam															
Virgin scraped..........	0.024	0.002	0.003	0.018	0.004	0.009	0.014	0.007	0.002	0.020	0.008	0.006	0.010	0.004	0.007
Virgin hoed............	0.030	0.013	0.004	0.018	0.005	0.006	0.013	0.006	0.002	0.015	0.011	0.007	0.008	0.008	0.004
Miami silt loam															
Virgin scraped..........	0.020	0.010	0.004	0.110	0.040	0.005	0.048	0.032	0.009	0.028	0.023	0.006	0.012	0.009	0.010
Virgin hoed............	0.027	0.007	0.008	0.024	0.013	0.014	0.004	0.015	0.006	0.018	0.017	0.013	0.018	0.011	0.012

that considerable soluble material was found at the surface of soil bearing certain crops which when carried below by rains would result in a stimulation of growth. This point has been referred to previously.

The data for the $\frac{1}{4}$ to 3-inch section show no consistent differences in the accumulation of soluble material as the result of plant growth. On October 5, however, the majority of the samples show more soluble salt in the uncropped soils. Since the first two samplings were made after periods of appreciable rainfall and the latter one October 5 after several days of practically no precipitation it seems that climatic conditions may be a factor. In the 3 to 9-inch sections the average of the results indicate a greater amount of soluble material in the plots devoid of vegetation. These results are substantially in accord with those for 1918 and 1919.

The influence of distributing the organic matter of several virgin soils through a somewhat thicker stratum by means of hoeing on the formation of soluble substances is shown in table 10.

The results are somewhat surprising in that they show no acceleration of the formation of solubles as a result of cultivation. These observations are in accord with those of last year but are interesting in that it seemed probable during the second year when more time had elapsed for decay to reach a more advanced stage that the production of soluble salts would be materially increased. It seems, therefore, that the tendency previously noted for more soluble material to accumulate in field soils free of vegetation than in the corresponding virgin soils, is not due to more thorough distribution of the organic matter or to increased aeration or distribution of organisms as a result of tillage.

SUMMARY

The data for 1919 afford additional evidence that the soluble salt content of the surface 6 inches of soils free of vegetation is quite low in the early spring and late fall but reaches a somewhat higher concentration sometime during the summer.

The salt content of the 6 to 12-inch section was usually quite low and showed no tendency to reach a maximum during summer.

Plant growth modified the amount of solubles in the $\frac{1}{4}$ to 6-inch section and tended to prevent the accumulation of soluble salts at the surface of the soil.

When no vegetation was present soluble substances tended to accumulate in the $\frac{1}{4}$-inch soil section, especially during dry periods.

The above observations offer further evidence in support of the conclusion previously published.

Rainfall was shown to be an important factor in the distribution of soluble materials in the soil strata. This problem is being investigated more in detail.

The data also indicate that factors other than rainfall materially influence the accumulation and distribution of salts in field soils.

The incorporation of the organic matter of several virgin soils throughout the surface 6-inch section by hoeing did not lead to a more rapid production of soluble material than was noted when these soils were maintained free of vegetation but not cultivated.

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ACID SOIL STUDIES: III. THE INFLUENCE OF CALCIUM CARBONATE, CALCIUM OXIDE, AND CALCIUM SULFATE ON THE SOLUBLE SOIL NUTRIENTS OF ACID SOILS

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This series of acid soil studies was undertaken to ascertain why some so-called "acid soils" of Oregon respond well to lime treatment while other acid soils do not show an increase in crop yields after the application of lime. Observations of both pot and field tests reveal the fact that even legumes, such as clover and field peas, do not show increased yields on certain limed acid soils referred to above. Various laboratory tests such as the determination of the acidity or lime requirement by several prevalent methods, chemical and physical analyses of the soils, and reactions with neutral salts do not disclose any particular abnormality in these soils. Consequently a more systematic study was undertaken to find some differential factor that would account for the unnatural action of those acid soils that do not respond to lime treatment.

In paper I (4) a study was made of the soil separates while in paper II (5) observations were made on the changes in calcium compounds added to the different types of acid soils, but no unusual results were obtained that would account for the anomalous behavior of some of them.

It is generally recognized that the application of lime to an acid soil improves its texture and creates a better medium for the optimum development of nitrifying and other beneficial organisms. Lime also supplies a necessary base and changes certain elements into a more available form. In promoting chemical and bacteriological functions it would necessarily change the composition of the soil solution. Since the applications of lime increased the crop yields on some of the soils under study while no effects were noted in others, it was thought that a study of the changes in the soluble soil nutrients of the several soils after treatment with lime might disclose information that would aid in solving the problem. Accordingly a study was made of the effects of calcium carbonate, calcium oxide, and calcium sulfate on the soluble nutrients of five different acid soils.

DESCRIPTION OF SOILS

The five so-called "acid soils" selected for study were representative of Willamette valley and coast lands of Oregon and varied greatly in their lime

requirement or acidity as indicated by the Veitch (8), Jones (3), and Hopkins (2) methods.   To discriminate between the different soils they were given the laboratory numbers 11076, 11077, 11078, 11079 and 11080.

Soil 11076 is classified as a Willamette silt loam and shows a lime requirement of 3200 pounds of calcium carbonate per acre.   This soil responds well to lime treatment and gave nearly 100 per cent increase in clover crop from the application of 1 ton of limestone per acre.

Soil 11077 is classified as a Salem gravelly loam and has a lime requirement of about 1 ton per acre.   No increase in either clover, barley, or field peas was obtained by the application of lime to this soil.

Soil 11078 is also a Willamette silt loam and is almost identical with soil 11076 in texture and lime requirement.   However, applications of lime did

TABLE 1

Physical analyses of soils

SOIL NUMBER	COARSE SAND	FINE SAND	SILT	CLAY
	per cent	*per cent*	*per cent*	*per cent*
11076	0.9	27.1	52.1	19.9
11077	25.6	42.0	22.5	9.9
11078	1.3	32.4	49.6	16.7
11079	28.5	26.5	29.2	15.8
11080	38.3	29.4	23.7	8.6

TABLE 2

The chemical analyses of soils

SOIL NUMBER	CaO	MgO	P_2O_5	K_2O	N	HUMUS
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
11076	0.69	0.11	0.35	2.50	0.213	2.35
11077	1.96	0.33	0.77	1.68	0.210	2.59
11078	0.53	0.24	0.22	3.03	0.216	2.35
11079	0.16	0.23	0.29	1.41	0.320	3.88
11080	0.34	0.41	0.07	0.79	0.364	4.60

not increase either clover or barley crops.   This soil is located on the west border of the Willamette Valley on the Experiment Station farm while soil 11076 is 12 miles distant directly across the Willamette Valley and on its east border.

Soil 11079 is classified as a brown clay loam and has a lime requirement of 5 tons per acre.   It responds well to lime treatment.

Soil 11080 is a medium sandy loam and is a representative type of a large area of coast lands.   It has a very high lime requirement of over 10 tons to the acre.   Applications of limestone at the low rate of 2 tons per acre gave more than 100 per cent increase in clover crop.

The following table shows the physical analyses of the different soils.   The coarse and medium sand were combined and listed as coarse sand, while the fine sand and very fine sand were combined and listed as fine sand.

Chemical analyses reporting the percentage of essential plant food elements are given in table 2.

It is apparent from the above analyses that all of the soils under investigation are deficient in both calcium and magnesium with, perhaps, the exception of soil 11077. On account of the small amount of these elements present in the soil it would seem that all of them would respond to lime treatment. The other plant food elements are comparatively high and from their standpoint the soils may be judged fertile.

<center>PROCEDURE</center>

The five different acid soils described above were collected in the early spring when the nitrate content was low. After they had been air-dried, they were sifted through a 10-mesh sieve, which was accomplished by crushing the larger lumps with a rubber tipped pestle. Two-thousand-gram portions were then weighed out and sufficient calcium carbonate was thoroughly incorporated in each lot to satisfy the lime requirement as determined by the Veitch (8) method. Similar portions of each soil were also treated with calcium oxide and calcium sulfate in amounts equivalent to the calcium employed in the calcium carbonate-treated lot. Owing to the excessive amount necessary, soil 11080 received only one-half of the calcium sulfate equivalent to the amount of calcium carbonate used in that soil. Similar amounts of the different soils untreated were used as controls. The prepared soils were then transferred to large wide-mouthed jars and enough distilled water was added to bring each soil to its optimum moisture content. This percentage of moisture was maintained throughout the experiment. The jars were kept in a room the temperature of which varied between 15° and 20°C.

In order to observe the effects of the various treatments on the different soils, determinations were made periodically of the soluble soil nutrients. The first determinations of the soluble soil nutrients were made after the treated soils had stood 24 hours. For convenience this is designated series 1. Subsequent analyses were made after the treated soils had stood 3 months and 6 months and are referred to as series 2 and series 3, respectively. For the determination of the soluble soil nutrients a soil solution was prepared by shaking at intervals during 8 hours, 1 part of dry soil with 5 parts of distilled carbon-dioxide-free water. Immediately preceding the preparation of the soil solution, the moisture content of each soil was determined and allowance was made for the water present. The soil was then allowed to stand over night after which it was centrifuged at high speed to settle particles and finally passed through a Pasteur-Chamberland filter. Calcium, magnesium, potassium, phosphorus, sulfates, nitrates and total solids were then determined in the solutions thus obtained.

Calcium, phosphorus and potassium were determined by methods suggested by Stewart (6) slightly modified to suit the work at hand. It was found

advantageous to take larger portions of the soil solution than recommended by Stewart especially for phosphorus and magnesium. Sulfates were precipitated as barium sulfate in a 400 cc. aliquot of the soil solution slightly acidified with hydrochloric acid. Nitrates were determined colorimetrically by the phenol-di-sulfonic acid method. The hydrogen-ion concentration was measured by the gas-chain method but it was found that after the first series, constant readings could not be obtained on account of the high nitrate content which apparently was reduced by hydrogen forming ammonia.

TABLE 3

Series 1. Composition of the soil solutions 24 hours after treatment

SOIL NUMBER	TREATMENT		PARTS PER MILLION OF SOIL SOLUTION						
	Material	Quantity	Solids	CaO	MgO	K_2O	P_2O_5	SO_3	NO_3
		per cent							
11076	Control		142.0	21.1	7.78	7.74	1.70	3.1	57.2
11076	$CaCO_3$	0.32	196.0	46.3	11.76	3.20	1.85	3.1	57.2
11076	CaO	0.18	167.0	35.9	8.32	4.31	1.71	3.1	54.7
11076	$CaSO_4 \cdot 2H_2O$	0.55	879.0	249.0	42.71	9.88	0.47	420.0	54.7
11077	Control		58.5	10.2	4.16	4.55	1.68	2.6	3.2
11077	$CaCO_3$	0.18	93.5	25.4	6.70	5.91	1.70	2.6	3.2
11077	CaO	0.10	91.0	23.7	6.52	5.81	1.65	5.2	3.2
11077	$CaSO_4 \cdot 2H_2O$	0.30	573.5	153.8	19.72	13.15	1.16	257.3	1.6
11078	Control		87.0	13.4	4.79	3.68	0.48	1.7	31.2
11078	$CaCO_3$	0.32	137.0	36.6	7.69	3.58	0.62	1.9	28.0
11078	CaO	0.18	132.0	28.4	5.79	3.24	0.81	3.1	28.4
11078	$CaSO_4 \cdot 2H_2O$	0.55	905.0	278.5	38.56	5.47	0.54	461.7	26.4
11079	Control		33.0	5.68	2.54	3.00	0.34	Trace	7.6
11079	$CaCO_3$	0.62	151.0	56.4	4.34	3.20	0.58	6.8	7.6
11079	CaO	0.35	116.0	30.8	1.90	1.55	0.54	7.9	6.0
11079	$CaSO_4 \cdot 2H_2O$	1.14	1429.0	459.5	57.35	6.60	0.31	790.6	5.2
11080	Control		125.0	13.9	6.50	6.40	0.27	Trace	5.9
11080	$CaCO_3$	1.55	354.5	115.0	15.65	6.90	0.39	4.8	9.6
11080	CaO	0.87	243.5	48.3	6.35	4.85	0.76	5.0	5.9
11080	$CaSO_4 \cdot 2H_2O$	1.34	1527.8	451.0	63.00	18.60	0.39	800.0	3.7

The analyses of the soil solutions made after 24 hours, after 3 months and after 6 months are reported in tables 3, 4 and 5, respectively. Since utmost precautions were taken to prepare the soil solutions of all soils for the three different series in a similar manner as described above and since it is desirable to compare the concentration of the soluble soil nutrients in the soil solution, the results in the following tables and all subsequent tables are reported as parts per million of the soil solution.

DISCUSSION

The results obtained in the first series, as reported in table 3, where the soil solution was prepared 24 hours after treatment shows mainly the chemical action of the different treatments on the solubility of the soil nutrients since adequate time had not elapsed to permit any beneficial or toxic effects on the soil organisms. In general there were no significant chemical reactions that would indicate an abnormal condition in any of the soils. As would be expected, the amount of solids or total soluble salts was greater in the treated

TABLE 4

Series 2. Compostion of soil solutions 3 months after treatments

SOIL NUMBER	TREATMENT		PARTS PER MILLION OF SOIL SOLUTION						
	Material	Quantity	Solids	CaO	MgO	K₂O	P₂O₅	SO₃	NO₃
		per cent							
11076	Control		179.5	26.4	10.32	7.45	1.93	3.4	78.0
11076	CaCO₃	0.32	197.0	45.2	9.80	5.23	0.97	4.5	84.0
11076	CaO	0.18	193.5	42.8	11.05	5.42	0.70	4.6	90.8
11076	CaSO₄·2H₂O	0.55	1005.5	285.5	50.50	11.34	0.48	455.0	90.4
11077	Control		83.0	14.4	4.98	6.30	1.97	3.4	30.8
11077	CaCO₃	0.18	98.0	20.7	4.61	4.94	1.06	3.4	30.8
11077	CaO	0.10	94.0	22.2	4.88	4.30	1.06	5.0	30.8
11077	CaSO₄·2H₂O	0.30	452.5	68.6	17.24	8.52	0.46	212.0	22.8
11078	Control		111.5	20.7	7.78	3.78	1.01	10.3	26.4
11078	CaCO₃	0.32	132.0	26.2	7.06	2.18	0.81	3.3	40.0
11078	CaO	0.18	112.5	24.6	6.79	2.08	0.87	3.5	44.0
11078	CaSO₄·2H₂O	0.55	909.0	283.6	42.55	4.60	0.57	450.0	33.2
11079	Control		55.5	7.7	3.71	4.65	0.41	Trace	17.2
11079	CaCO₃	0.62	138.5	37.5	1.99	2.52	0.43	7.4	43.6
11079	CaO	0.35	130.2	33.9	None	2.23	0.34	7.5	40.0
11079	CaSO₄·2H₂O	1.14	1408.5	426.3	66.65	4.84	0.34	739.0	17.0
11080	Control		168.0	24.8	10.60	8.12	0.46	Trace	11.6
11080	CaCO₃	1.55	305.0	80.0	10.05	4.56	0.51	5.5	50.0
11080	CaO	0.87	326.0	82.0	9.90	5.04	0.64	5.7	43.6
11080	CaSO₄·2H₂O	1.34	1638.0	471.5	66.50	15.85	0.33	816.5	0.9

soils than in the untreated controls. Any increase would represent the solubility of the substances used in the treatments and the solvent effects of the dissolved salts on the soil. Both calcium carbonate and calcium oxide treatments increased the soluble calcium in all soils, the former giving appreciably higher amounts, especially in soil 11080. The calcium carbonate treatment likewise increased the soluble magnesium in all soils while the calcium oxide treatment gave smaller increases in magnesium for soils 11076, 11077 and 11078 and slight decreases in soils 11079 and 11080. Even greater quantities

of magnesium were rendered soluble by the calcium sulfate treatment. The calcium sulfate treatments also increased the solubility of potassium in all soils which confirms similar results obtained by other workers. Attention is called to the abnormally low amounts of phosphates and sulfates which do not show differences worthy of note.

In the second series where the soil solution was prepared after chemical and biological activities had progressed 3 months more significant changes had occurred. The most important changes are seen in the effects of calcium

TABLE 5

Series 3. Composition of soil solutions 6 months after treatments

SOIL NUMBER	TREATMENT		PARTS PER MILLION OF SOIL SOLUTION						
	Material	Quantity	Solids	CaO	MgO	K₂O	P₂O₅	SO₃	NO₃
		per cent							
11076	Control		217.0	31.8	11.05	7.36	0.81	4.0	84.0
11076	CaCO₃	0.32	257.8	56.9	11.20	5.28	1.09	6.4	124.8
11076	CaO	0.18	237.8	50.0	12.45	6.01	1.19	5.7	116.0
11076	CaSO₄·2H₂O	0.55	918.2	264.1	45.40	10.85	0.68	417.5	68.0
11077	Control		124.2	24.8	17.85	6.05	0.96	3.4	56.0
11077	CaCO₃	0.18	135.8	27.9	16.55	5.01	1.12	4.5	52.8
11077	CaO	0.10	140.0	29.3	17.75	5.76	0.96	6.0	55.2
11077	CaSO₄·2H₂O	0.30	429.0	145.6	17.55	8.38	0.69	205.3	37.6
11078	Control		126.0	22.1	9.55	2.71	3.09	3.2	50.0
11078	CaCO₃	0.32	148.5	34.6	8.40	2.35	2.24	3.4	68.0
11078	CaO	0.18	162.0	31.8	6.15	1.79	2.32	4.6	67.2
11078	CaSO₄·2H₂O	0.55	971.5	295.0	38.50	4.94	0.54	460.0	50.8
11079	Control		88.0	13.7	2.98	3.05	0.70	0.7	36.8
11079	CaCO₃	0.62	173.7	46.9	None	1.45	0.39	6.2	80.8
11079	CaO	0.35	174.2	46.9	None	1.21	0.12	6.0	80.0
11079	CaSO₄·2H₂O	1.14	1560.2	441.0	66.40	5.85	None	755.0	36.0
11080	Control		309.5	39.9	17.30	8.18	0.15	Trace	58.0
11080	CaCO₃	1.55	444.8	105.5	13.70	5.33	0.37	7.7	171.2
11080	CaO	0.87	464.0	110.2	13.75	5.33	None	7.7	166.0
11080	CaSO₄·2H₂O	1.34	1805.2	494.0	99.10	16.86	None	905.5	16.0

carbonate and calcium oxide on the production of nitrates in the different soils. In all five types the untreated controls showed an increase in nitrates which varied in amounts with the different soils. Nitrates developed in appreciable amounts in the controls of soils 11076 and 11077 but only to a very limited extent in soils 11078, 11079 and 11080. On the other hand the calcium carbonate and calcium oxide treatments of soils 11079 and 11080 increased the nitrates four-fold and seven-fold respectively, while soil 11077, which does not respond to lime applications, gave no increase in nitrates with similar

treatment. Soil 11078, which also does not respond to applications of lime. did not show a very great increase in the amount of nitrates formed in the calcium carbonate and calcium oxide treated pots. Again, soil 11076, which responds to applications of lime, showed a larger amount of nitrates in the calcium carbonate and calcium oxide treated pots than in the control. These results indicate that the nitrification processes are stimulated by calcium carbonate and calcium oxide in those acid soils that respond to lime treatment but the formation of nitrates is not so great in those soils that do not respond to lime treatment.

Further examination of table 4 shows that the calcium sulfate treatment increased the nitrates in soil 11076 but seemed to have a depressing effect on the nitrification processes in the others. No consistent changes are apparent in the other soluble soil nutrients that might indicate any differential characteristics.

Table 5 reports the amounts of soluble nutrients in the different soils 6 months after treatment. Again we note the favorable influence of calcium carbonate and calcium oxide on the development of nitrates in those soils that respond to lime treatment. As in series 2 the untreated controls of all soils showed an increase in nitrates. In soils 11076, 11079 and 11080, however, far greater amounts of nitrates were produced in the calcium carbonate and calcium oxide treated pots than in the controls. On the other hand, soil 11077 showed smaller amounts of nitrates in the calcium carbonate and calcium oxide treated pots than in the control and soil 11078 showed comparatively small increases in the treated pots. These results further substantiate those obtained in series 2, that the nitrification processes are greatly stimulated by calcium carbonate and calcium oxide in those soils that respond to lime treatment and to a less extent in those soils that do not respond to lime treatment.

As in the previous series no definite statements can be made regarding the effects of the different treatments on the other soluble soil nutrients. It will be observed that the total soluble salts increased over the amount found in series 2. With a few exceptions the soluble calcium and magnesium increased in both treated and untreated soils. Both phosphates and sulfates were low as in the first two series.

It is of interest to note that the effect of calcium sulfate treatment on the solubility of potassium was approximately constant throughout the three series. This indicates that the action of calcium sulfate on the solubility of potassium is a chemical reaction and is not influenced greatly by bacteriological changes.

Considering the results of the three series from the standpoint of a possible reason for two of the acid soils not responding to lime treatment in actual field tests, it is apparent that the nitrification processes and conditions that influence them are the most potent factors. The supply of an abundance of nitrates available at the right time would doubtlessly increase crop yields, while a deficiency would not permit optimum growth.

THE EFFECTS OF PHOSPHATES UPON NITRIFICATION

It is evident from the above results that the available phosphorus in all the soils is exceedingly low. Stoddart (7), and Conner (1) emphasized the need of acid soils in general for available phosphates. It is possible that the two acid soils under study which do not respond to lime treatment may contain excessive amounts of iron and aluminum salts and that the treatment with calcium carbonate or oxide does not destroy entirely their toxic properties sufficiently to permit favorable conditions for the optimum development of nitrifying organisms.

To learn whether the application of phosphates would overcome a possible toxicity and permit more rapid formation of nitrates, especially in soils 11077 and 11078, treatments of the different soils were made using mono-calcium phosphate, mono-calcium phosphate plus calcium carbonate, and tri-calcium phosphate. Convenient amounts of the soils were taken and the phosphates added at the rate of about 600 pounds per acre. A composite infusion prepared from the fresh soils was added to distilled water and was used to maintain the moisture content. The nitrates were determined in soils 11076, 11077, and 11078 after standing 6 weeks at 26° to 30°C. temperature while soils 11079 and 11080 stood 2 weeks. Table 6 records the treatment and amount of nitrates formed in parts per million of soil solution.

The results cited above present some interesting data. It will be observed that soil 11078, which does not respond to lime treatment, showed increased formation of nitrates when treated with mono-calcium phosphate and still greater amounts when treated with mono-calcium phosphate plus calcium carbonate. Calcium carbonate alone and the insoluble tri-calcium phosphate had no beneficial effects. On the other hand treatment of soils 11076, 11079 and 11080, with phosphates did not have a beneficial effect. In fact the mono-calcium phosphate had a depressing effect on the formation of nitrates. Substantiating previous results these soils showed large increases in nitrates due to calcium carbonate treatment. In soil 11077 the formation of nitrates was stimulated slightly by phosphate treatment.

Since mono-calcium phosphate stimulated nitrate formation in soil 11078 in pot tests, it was thought desirable to learn whether similar results would be obtained under field conditions. Accordingly small plots were prepared which received treatments of limestone, mono-calcium phosphate and mono-calcium phosphate plus limestone. The limestone was applied at the rate of 2 tons per acre and the phosphate at the rate of 200 pounds per acre.

In order to compare under similar conditions in the field the formation of nitrates in one of the soils that responds to lime treatment, sufficient fresh soil of number 11076 was obtained and beds 6 inches deep were prepared near soil 11078. One plot was left untreated while the other received an application of limestone at the rate of 2 tons per acre. Beginning April 1, samples were taken at intervals from the several plots and the nitrates determined. Table 7 reports the results obtained in parts per million of soil solution.

TABLE 6

The effect of phosphates upon nitrification

SOIL NUMBER	TREATMENT		NITRATES IN SOIL SOLUTION
	Material	Quantity	
		per cent	*p.p.m.*
11076	Control		316.0
11076	CaCO₃	0.25	380.0
11076	CaH₄(PO₄)₂	0.10	304.0
11076	CaH₄(PO₄)₂+CaCO₃	0.10 + 0.25	252.0
11076	Ca₃(PO₄)₂	0.15	276.0
11077	Control		152.0
11077	CaCO₃	0.10	144.0
11077	CaH₄(PO₄)₂	0.10	156.8
11077	CaH₄(PO₄)₂+CaCO₃	0.10+ 0.10	148.0
11077	Ca₃(PO₄)₂	0.15	144.0
11078	Control		178.0
11078	CaCO₃	0.25	168.0
11078	CaH₄(PO₄)₂	0.10	227.5
11078	CaH₄(PO₄)₂+CaCO₃	0.10+ 0.25	295.0
11078	Ca₃(PO₄)₂	0.15	160.0
11079	Control		66.8
11079	CaCO₃	0.56	118.0
11079	CaH₄(PO₄)₂	0.10	48.0
11079	CaH₄(PO₄)₂+CaCO₃	0.10+ 0.56	122.4
11079	Ca₃(PO₄)₂	0.15	60.0
11080	Control		7.2
11080	CaCO₃	0.70	72.8
11080	CaH₄(PO₄)₂	0.10	20.0
11080	CaH₄(PO₄)₂+CaCO₃	0.10+ 0.70	54.8
11080	Ca₃(PO₄)₂	0.15	12.0

TABLE 7

Nitrates formed in soils under field conditions

SOIL NUMBER	TREATMENT	NITRATES IN SOIL SOLUTION					
		April 1	April 15	April 23	May 2	May 9	May 22
			p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
11076	Control	Trace	11.2	18.4	32.5	4.9	14.1
11076	CaCO₃	Trace	16.3	26.0	43.2	8.0	24.1
11078	Control	Trace	4.8	8.4	13.2	2.8	6.0
11078	CaCO₃	Trace	5.1	9.2	14.1	2.6	6.2
11078	CaH₄(PO₄)₂	Trace	4.6	8.0	13.0	2.0	5.4
11078	CaH₄(PO₄)₂+CaCO₃	Trace	5.0	8.8	14.0	2.4	6.0

The development of nitrates under field conditions was similar to the pot experiments with respect to the calcium carbonate treatment but the influence of phosphates in the field tests did not confirm the results obtained in the pot tests.   The inability to thoroughly mix the phosphate with the moist soil in the early spring may account for the failure to get the results anticipated. It is interesting to note that during the week between May 2 and May 9 there was a denitrification period that was consistent in all plots.   At that particular time the weather was cold and somewhat wet which was probably conducive to denitrification.   Attention is called to the comparative rapidity with which the nitrates formed in the two different soils treated with calcium carbonate.   Both in the early spring and immediately following the denitrification period, soil 11076 formed large amounts of nitrates while soil 11078 acted much more slowly and gave but little increase due to the calcium carbonate treatment.   When it is remembered that soil 11076 gives an increase in crop yields upon application of lime and that soil 11078 does not, it is evident that the rapid development of sufficient nitrates is an important influencing factor that may explain why one acid soil responds while another does not respond to lime treatment.

Work is being continued to ascertain why nitrates do not increase, as may be expected, in some acid soils after treatment with lime.

SUMMARY

A study has been made of the soil solution of five so-called "acid soils," three of which give increased crop yields from the application of lime while two do not.

Periodic determinations have been made of the water-soluble nutrients of these soils after treatment with $CaCO_3$, CaO and $CaSO_4$.

The main differential factor was the rapid development of a comparatively large amount of nitrates due to treatment with calcium carbonate or calcium oxide in those soils that respond to lime treatment while the other soils show much smaller increase in nitrates after similar treatment.

The water-soluble phosphorus and sulfur were very low in all soils and did not change appreciably due to the effects of the various treatments.

Treatment of all soils with calcium sulfate increased the water-soluble magnesium and potassium.

In pot experiments mono-calcium phosphate, and mono-calcium phosphate plus lime caused an increase in nitrates in those soils that do not show an increase to lime treatment alone.   Field plot tests did not confirm these results.

Periodic determinations of nitrates in field plots showed that soil 11076, nitrifies rapidly when treated with limestone while soil 11077 showed very little increase.

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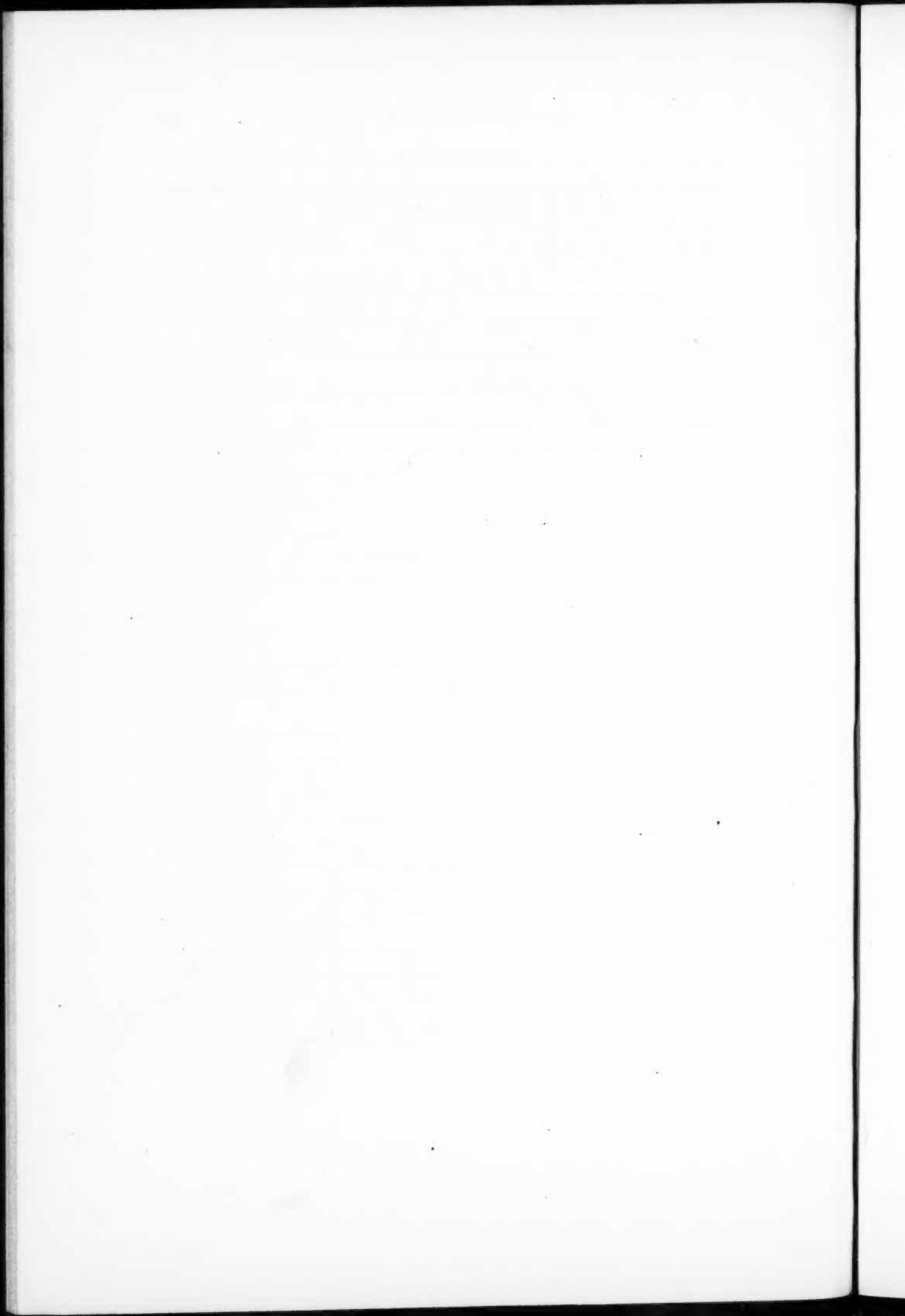
THE EFFECT OF LIME, LEACHING, FORM OF PHOSPHATE AND NITROGEN SALT ON PLANT AND SOIL ACIDITY, AND THE RELATION OF THESE TO THE FEEDING POWER OF THE PLANT.

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The study of the acidity of plant juices in relation to the supply of plant-food and the feeding power of the plant is a step in the direction of a clearer understanding of the relations of a plant to its environment. It is only recently that problems of this nature have been given any special attention. Hoagland (5) has carried on some studies on the relation of the nutrient solution to the composition and reaction of the cell sap of barley. Truog and Meacham (8) have reported some studies on the relation of soil acidity to the acidity of plant juices, and Clevenger (2) has studied some of the factors affecting the acidity of plant juices. The present investigation was undertaken to study the effect of limestone, leaching, form of phosphate and nitrogen salt on plant and soil acidity, and the relation of these to the feeding power of the plant.

EXPERIMENTAL

Plan of work

For this investigation, corn and soybeans were grown in quartz cultures with suitable nutrients. The corn cultures were grown by one of us in an investigation previously reported. For the details regarding the plan of these cultures the reader is referred to the previous paper (1). The general plan of the soybean cultures was quite similar. Some minor differences in the fertilizer treatments of the corn and the soybean are indicated in table 1.

Fifteen inoculated soybean seeds were planted in each 2-gallon pot and shortly thereafter thinned to the best 10 plants. The cotyledons were removed from the seedlings in order to hasten the appearance of differences in growth due to the various treatments. Each treatment was made in duplicate.

TABLE 1

Weight, water content, and acidity of different parts of soy-bean plants, and acidity of soil extracts secured under treatments indicated

POT NUMBER	TREATMENTS*	WEIGHT				WATER AS PERCENTAGE OF GREEN WEIGHT		REACTION OF PLANT JUICE						REACTION OF SOIL EXTRACT
		Green		Air-Dry				Leaves	Stems and petioles	Roots			Nodules	
										Actual acidity	0.0684 N alkali added			
		Tops	Roots	Tops	Roots	Tops	Roots				1 cc.	2 cc.		
								pH	pH	pH	pH	pH	pH	pH
		gm.	gm.	gm.	gm.	per cent	per cent							
105	None.............	19.6	38.4	3.6	2.3	81.6	94.0	6.17	6.07	6.36	8.12	8.58		7.43
107	Acid phosphate.........	90.8	62.9	17.2	4.4	81.0	93.0	5.82	5.50	6.33	8.36	9.59	6.31	8.00
109	Rock phosphate.........	36.3	46.4	7.4	2.9	79.6	93.8	5.99	6.21	6.58	8.27	8.69		8.15
111	Acid phosphate limestone (2 tons)......	92.5	70.0	19.4	5.0	79.0	92.8	6.01	6.16	6.31	8.14	9.39	6.85	7.85
113	Rock phosphate limestone (2 tons)......	32.1	43.3	6.4	3.0	79.9	93.1	6.38	6.48	6.31	8.31	8.98		8.31
115	Acid phosphate limestone (10 tons)......	90.1	72.3	16.9	5.2	81.4	92.7	5.99	5.82	6.33	8.58	9.86		8.17
117	Rock phosphate limestone (10 tons)......	28.9	45.0	5.4	3.4	80.7	92.4	6.61	6.21	6.42	8.07	8.61		8.43

* Rates of application on acre basis were: acid phosphate, 400 pounds; rock phosphate 2,000 pounds; and lime in the amounts indicated.

Just as they were beginning to open their flowers, the soybean plants were harvested. Their general appearance at this time is indicated in plate 1. Just before harvesting, the pots were leached with distilled water until 1 liter of drainage water was secured from each. These solutions were filtered immediately through Pasteur-Chamberland clay filters and determinations of the actual acidity were made. As the plants were harvested, portions were retained for dry-matter determinations.

The determinations of the acidity or hydrogen-ion concentration of the plant juices were carried out by the method previously described by one of us (3). Determinations were made on the leaves, the stems and petioles together, and the roots. The determinations were not made on the tops as a whole since it has been shown by one of us (4) that the reaction of the different parts may vary and that the proportion of leaves, petioles, and stems may thus be a factor influencing the values for the tops.

Growth and acidity of soybeans

The results from the soybean cultures are summarized in table 1 and shown graphically in figure 1. They clearly bring out the influence of an excess of carbonate on the availability of phosphates to the growing plant. The use of 2 tons of limestone with acid phosphate increased the yield over acid phosphate alone, in which case a lack of calcium carbonate probably prevented a more rapid plant growth. When 10 tons of limestone was used with acid phosphate there was a smaller yield than when no limestone was used. Here there was probably too much calcium carbonate present, which held up the availability of the phosphate to the plant. The production of roots increased with increased amounts of limestone, due possibly to increased activity, with lessening availability of the phosphate. In the case of the rock phosphate, increased amounts of limestone resulted in a smaller production of tops and a greater production of roots due to the increased difficulty of securing phosphorus. The lack of phosphorus was apparently reflected directly in the smaller production of tops; whereas the roots were stimulated to slightly greater activity. In every case the yields with acid phosphate were greater than those with rock phosphate.

Under the conditions indicated, the addition of calcium carbonate to the soil should be reflected in the reaction of the soil extract. The data show that this was the case. Although in every case the soil extract was alkaline, it was more alkaline when rock phosphate was used than when acid phosphate was used. Where rock phosphate was used, the greater the addition of limestone the more alkaline was the soil extract in all cases. Similarly with acid phosphate, the greatest alkalinity occurred when used with 10 tons of limestone, but strangely there was a less alkalinity when 2 tons of limestone was used than when none was used. This peculiar behavior of the soil extract was related to the growth of the plants in that the best growth was obtained with 2 tons of limestone. Evidently the more vigorous growing plants re-

FIG. 1. DIAGRAM OF DATA FROM SOYBEAN CULTURES SHOWING EFFECT OF LIMESTONE AND
FORM OF PHOSPHATE ON THE WEIGHT OF DRY MATTER AND REACTION OF THE
PLANT JUICES AND SOIL EXTRACT

moved the soluble basic material more rapidly from the soil and thus brought about the decreased alkalinity.

With the increase of calcium carbonate, it might be expected that more of this compound would be assimilated by the growing plant, and as suggested by Truog (7), acids in the plant would be neutralized and precipitated. The data indicate that in general this was true. In every case the juices from the three parts of the plant were more acid when acid phosphate was used than when rock phosphate was used. The juice from the leaves in general was less acid with increased amounts of limestone, regardless of the form of phosphate. The juices of the other portions of the plants, however, did not show this regularity. With either form of phosphate the root juice was the most acid when 2 tons of limestone was used, which is the same relation as noted above for the acidity of the soil extract and the growth of the plants with acid phosphate, while the juice of the stems and petioles was least acid when 2 tons of limestone was used.

In addition to determining the actual acidity of the root juices, determinations were made also of the pH values of the juices after adding a definite amount of standard alkali to a given amount of juice. These data make possible comparisons as to the relative amount of acid in the plant juices. After 1 cc. of alkali was added, the root juice from plants grown in pots 109 and 117 with rock phosphate was less alkaline than the root juices from plants grown in pots 107 and 115 with acid phosphate; when 2 cc. was added the same relation still held. The root juice from the plants of pot 113 treated with rock phosphate and 2 tons of limestone was more alkaline than that of pot 111 treated with acid phosphate and 2 tons of limestone; when a total of 2 cc. of alkali was added this relation was reversed.

By means of the small hydrogen electrode vessel described by one of us (4), it was possible to determine the actual acidity of the juice of the soybean nodules. It was only possible to make these determinations on the nodules from two cultures; namely, those in which acid phosphate was used with no limestone, and with 2 tons of limestone. Without the use of limestone the actual acidity of the juice from the nodule protoplasm did not differ markedly from the actual acidity of the juice of the roots upon which the nodules grew. When 2 tons of limestone was used in addition to the acid phosphate, the juice of the nodule protoplasm became much less acid than the juice from the roots upon which the nodules grew. In this respect, the juice from the nodule protoplasm varied in about the same manner as the juices of the top portions of the plants.

Growth and acidity of corn

The dry matter yields and acidity determinations for the corn cultures are summarized in table 2 and shown graphically in figure 2.

The amount of dry matter produced varied widely with the different treatments. Leaching the cultures once a week always increased the yield when

TABLE 2

Weight of dry matter and acidity of the different parts of the corn plant and soil extract secured under the treatments indicated

POT NUMBER	TREATMENTS*	DRY MATTER		REACTION OF PLANT JUICES									ACTUAL ACIDITY OF SOIL EXTRACT
				Leaves			Stalks			Roots			
				Actual acidity	Total acidity†		Actual acidity	Total acidity		Actual acidity	Total acidity		
		Tops	Roots	pH	Litmus	Phenol-phthal-ein	pH	Litmus	Phenol-phthal-ein	pH	Litmus	Phenol-phthal-ein	pH
		gm.	gm.		cc.	cc.		cc.	cc.		cc.	cc.	
35	None	1.9	1.2	5.36	3.25	4.75	5.36	1.30	2.10	6.04	0.75	1.75	7.17
37	Acid phosphate, NaNO₃, unleached	45.2	13.3	5.31	3.92	5.27	5.31	1.44	2.32	5.88	0.92	1.80	5.77
45	Acid phosphate, NaNO₃, leached	39.0	8.4	5.36	3.80	5.17	5.67	1.17	2.03	6.02	0.29	0.93	8.18
39	Rock phosphate, NaNO₃, unleached	18.3	6.2	5.31	4.32	5.92	5.62	1.37	2.32	5.87	0.57	1.37	6.70
47	Rock phosphate, NaNO₃, leached	23.4	6.9	5.31	1.92	3.75	5.95	0.34	1.03	5.65	0.51	1.28	4.23
41	Acid phosphate, NH₄NO₃, unleached	31.2	6.0	5.41	3.24	6.19	5.48			5.21	0.68	1.76	3.64
49	Acid phosphate, NH₄NO₃, leached	7.0	3.0										
43	Rock phosphate, NH₄NO₃, unleached	38.8	8.2	5.49	1.92	3.98	5.60	0.80	2.37	5.64	0.51	1.24	4.74
51	Rock phosphate, NH₄NO₃, leached	58.9	10.5	5.45	3.10	5.71	5.58	0.98	2.35	5.48	0.96	2.60	4.46

* Rates of application on acre basis were: acid phosphate, 400 pounds; and rock phosphate, 2000 pounds.

† Total acidity expressed in terms of cubic centimeter of 0.0684 N NaOH.
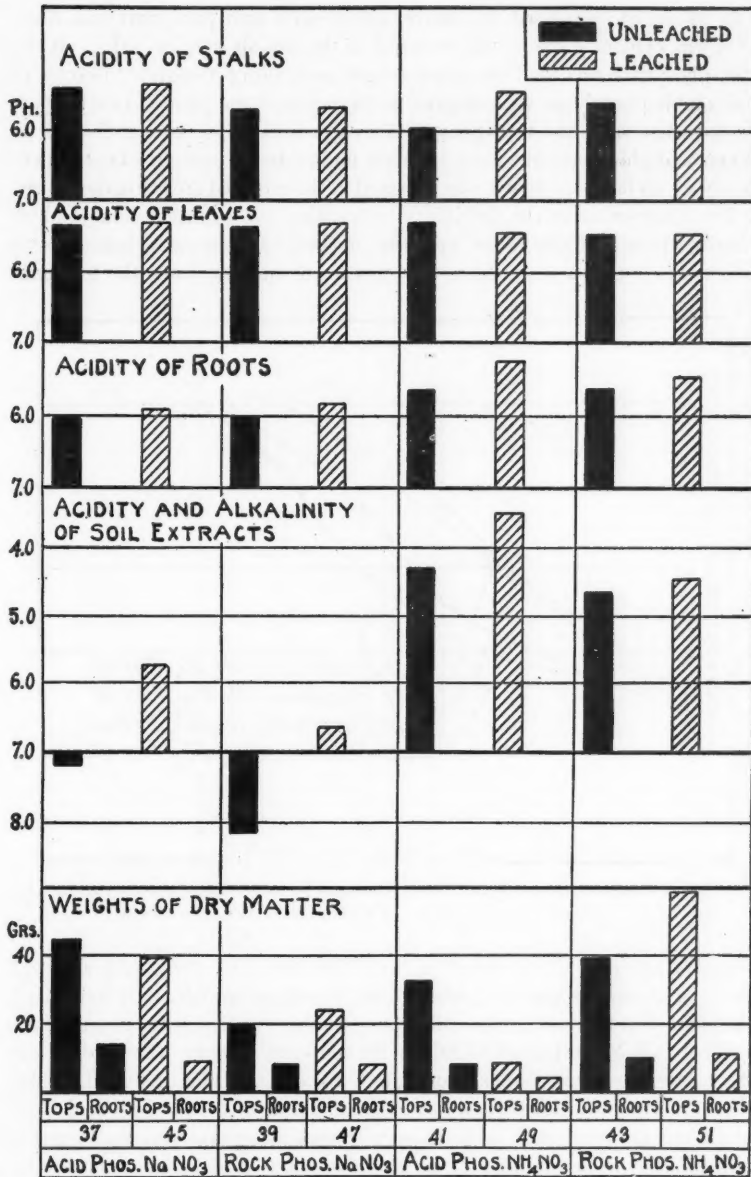
FIG. 2. DIAGRAM OF DATA FROM CORN CULTURE SHOWING THE EFFECT OF LEACHING, AND FORM OF NITROGEN SALT AND PHOSPHATE ON THE WEIGHT OF DRY MATTER AND REACTION OF THE PLANT JUICE AND SOIL EXTRACT

rock phosphate was used and decreased it when acid phosphate was used. This was evidently due to the removal of the soluble calcium salts. When rock phosphate was used the calcium salts were proportionately in excess of the soluble phosphate, with respect to the needs of the plant. Leaching removed these salts and thus permitted greater availability of the phosphate. When acid phosphate was used, leaching undoubtedly brought about a deficiency of calcium salts which was reflected in the retarded growth of the plants.

The question as to the possibility of leaching out sufficient soluble phosphorus where acid phosphate was used to limit plant growth, because of a deficiency of phosphorus, cannot be answered directly, since the leachings
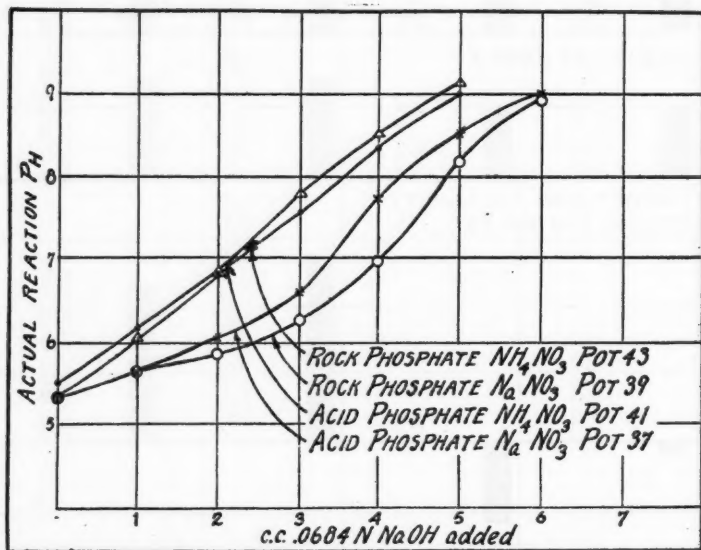
FIG. 3. CURVES SHOWING THE TOTAL ACIDITY OF THE JUICE OF CORN LEAVES AND SHEATHS GROWN IN UNLEACHED SOIL, IN TERMS OF CUBIC CENTIMETERS OF 0.0684 N NaOH

were not analyzed for phosphorus. It will be noted however, that, although leaching decreased the yield where acid phosphate and $NaNO_3$ were used, the yield from this culture was still among the best secured in the experiment.

When NH_4NO_3 replaced $NaNO_3$ as the source of nitrogen, the yields of dry matter were larger with rock phosphate than with acid phosphate. Leaching the soil increased this difference to the extent that the yields with acid phosphate became very small, while those with rock phosphate were the largest of any secured in the experiment. It is evident that NH_4NO_3 had a marked influence on the availability of the rock phosphate. This influence may have been due to one or more reasons; namely, its effect on the solubility of calcium

bicarbonate and its effect in increasing the acidity of the medium by becoming nitrified or acting as a physiologically acid salt.

The striking differences in plant growth due to the various treatments were accompanied with striking differences in the acidity of the soil extract. Leach-
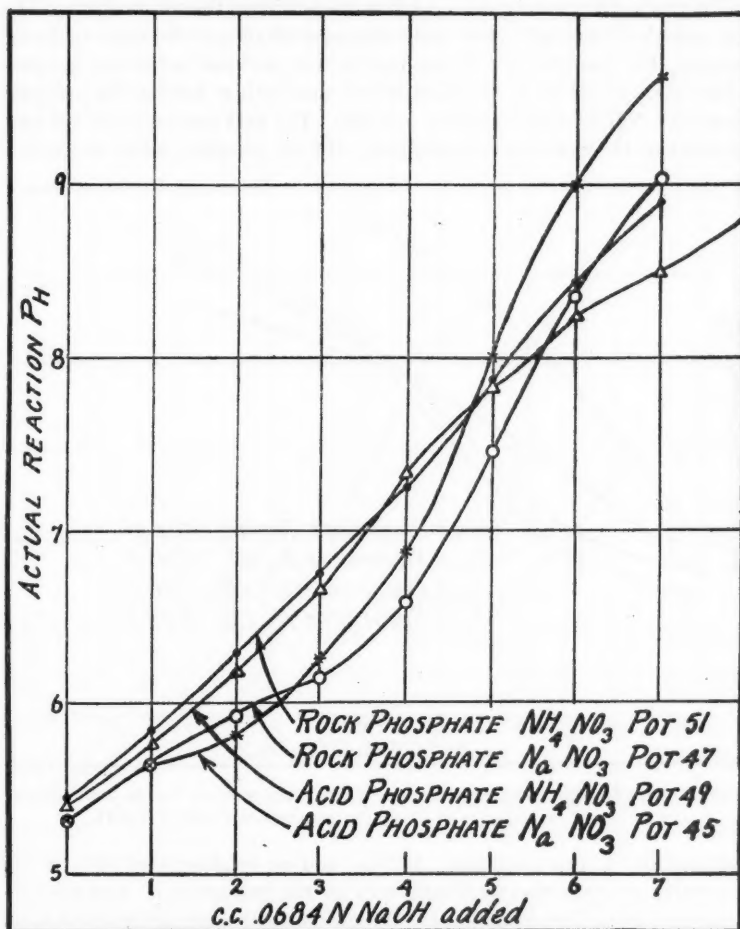
FIG. 4. CURVES SHOWING THE TOTAL ACIDITY OF THE JUICE OF CORN LEAVES IN LEACHED SOIL, IN TERMS OF CUBIC CENTIMETERS OF 0.0684 N NaOH

ing always increased this acidity and the greatest increase occurred when rock phosphate was used with NaNO$_3$. This increase in acidity readily explains why rock phosphate was made more available to corn by leaching. The soil extract was always more acid where acid phosphate was used in place of roc

phosphate.   Ammonium nitrate always made the soil extract more acid than
NaNO₃.   The greatest difference in reaction of soil extract occurred between
pot 39, treated with rock phosphate, but not leached, and pot 49, treated with
acid phosphate and leached.

The yields of dry matter did not follow the acidity of the soil medium.   The
best growth did not take place under the most alkaline or the most acid con-
ditions.   The poorest yield of dry matter was produced where the greatest
actual acidity, pH 3.64, prevailed which was with a combination of acid
phosphate, NH₄NO₃, and leaching (pot 49).   The next poorest yield was pro-
duced where the most alkaline condition, pH 8.18, prevailed, which was with a
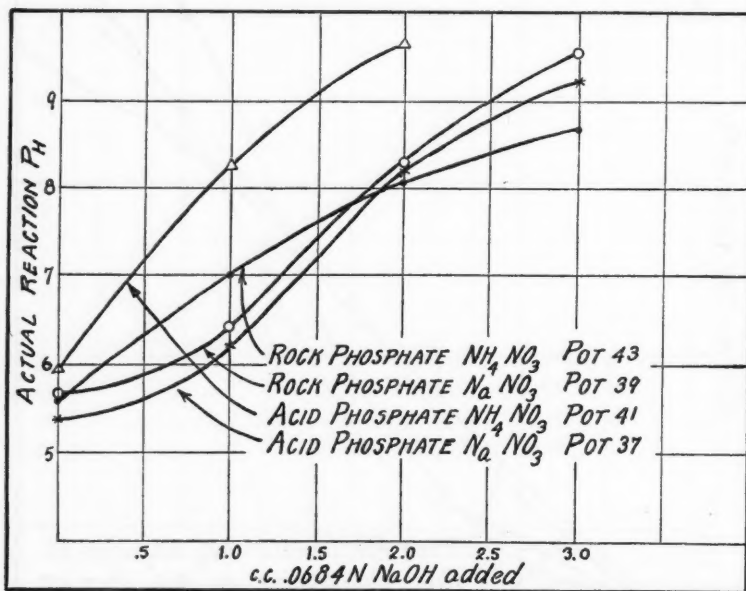
FIG. 5. CURVES SHOWING THE TOTAL ACIDITY OF THE JUICE OF CORN STALKS IN UNLEACHED
SOIL IN TERMS OF CUBIC CENTIMETERS OF 0.0684 N NaOH

combination of rock phosphate, NaNO₃, and no leaching (pot 39).   These
two extremes of reaction were not suited for the best growth.   The one pro-
duced such an acid reaction that physiological disturbances followed; the other
so alkaline a reaction that the plant was unable to get sufficient phosphorus
from the insoluble phosphate.   Under the conditions of this experiment the
best growth took place where the soil extract had a pH value of 4.46 (pot 51),
and the next best where the pH value was 7.17 (pot 37).   Evidently there is
quite a wide range of acidity under which the plant may grow well, but
the best conditions are well within the extremes made possible by fertilizer
treatment.

The marked differences in the acidity of the soil were reflected in the acidity of the plant juice, though the variations in the plant were not so marked. In all cases except one, leaching caused greater acidity in the plant juice. The most striking differences due to leaching were found in the root and stalk

ROCK PHOSPHATE $NH_4 NO_3$ POT 51
ROCK PHOSPHATE $Na NO_3$ POT 47
ACID PHOSPHATE $Na NO_3$ POT 45
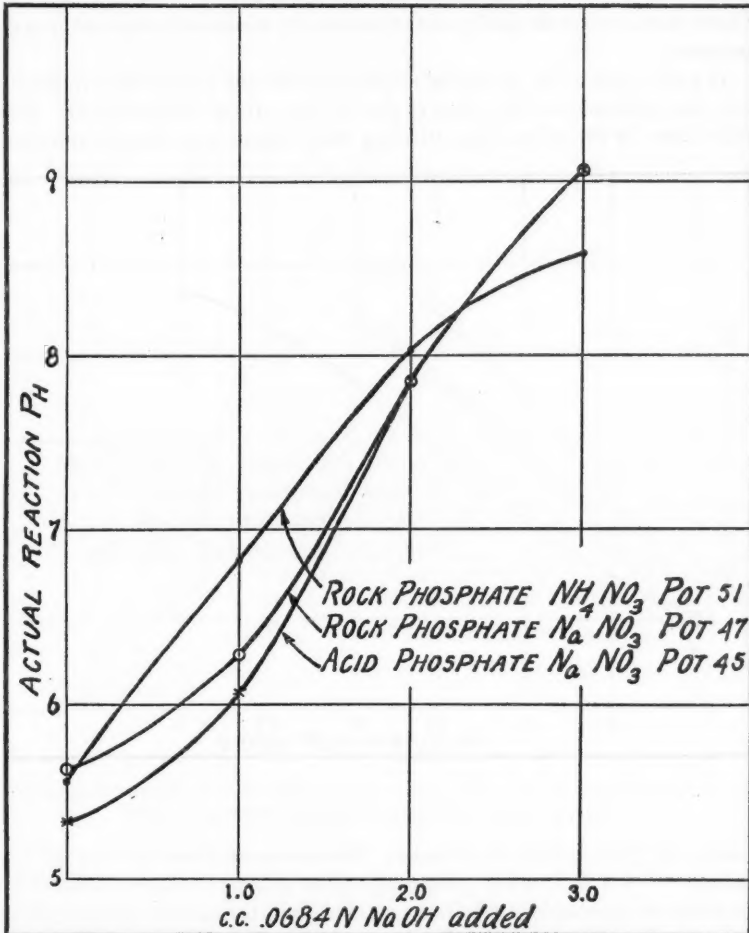
FIG. 6. CURVES SHOWING THE TOTAL ACIDITY OF THE JUICE OF CORN STALKS IN LEACHED SOIL, IN TERMS OF CUBIC CENTIMETERS OF 0.0684 N NaOH

juice of pots 41 and 49, treated with acid phosphate and NH_4NO_3. Neither acid phosphate nor rock phosphate influenced the acidity of the plant juices to a marked extent. In general, acid phosphate produced a slightly more acid condition in the plant. Ammonium nitrate as compared to $NaNO_3$, in-

creased the acidity of the root juice, but had little effect on the acidity of the tops, where in some cases there was even less acidity than with NaNO₃. In general the acidity of the root juice followed that of the soil, though the variations were not so wide as with the soil. The top portions of the plants were much more uniform in reaction, on account of the ability of these parts of the plants to counteract the acidity of environment by means of buffers and growth processes.

In table 2 are given the actual acidity and also the total acidity to litmus and phenolphthalein of the juices of the various parts of the corn plant. The pH values for the juices, after titrating with various quantities of standard
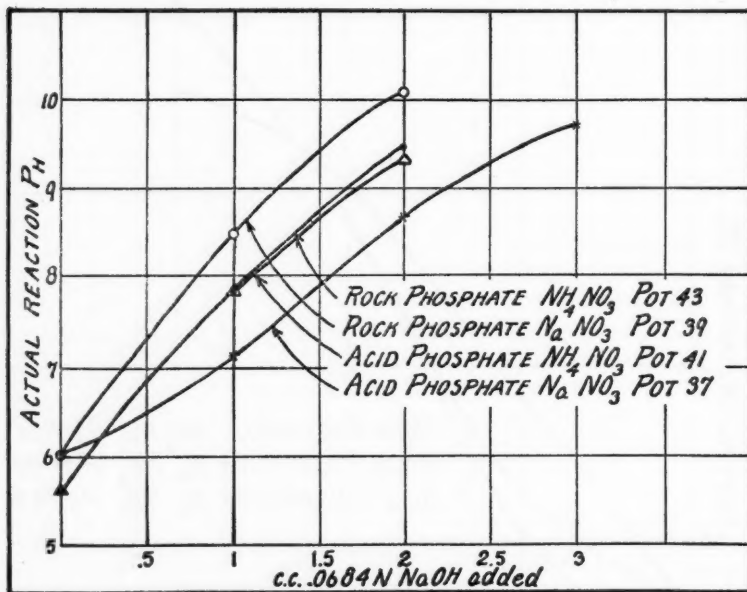
FIG. 7. CURVES SHOWING THE TOTAL ACIDITY OF THE JUICE OF CORN ROOTS IN UNLEACHED SOIL, IN TERMS OF CUBIC CENTIMETERS OF 0.0684 N NaOH

alkali, are given in tables 3, 4, and 5. The curves for these data are plotted in figures 3, 4, 5, 6, 7, and 8. The total acidity to litmus and phenolphthalein in terms of the standard alkali was secured from the curves. Litmus turns color at pH 6.81 and phenolphthalein at pH 8.3. Consequently, to determine the total acidity, according to these indicators it is only necessary to follow the ordinates to these points and from them the abscissae to the points where they are intercepted by the curve for any particular case. The length of the abscissa expressed in terms of cubic centimeters of 0.0684 N NaOH, is the value placed in table 2 for the total acidity to either litmus or phenolphthalein. Obviously from the curves, it is possible to secure the total acidity to any

indicator color change if it is known at what pH value the color change takes place.

The data for the total acidity of the juice of the corn plant follow the direction of those for the actual acidity. In 42 out of a total of 44 determina-
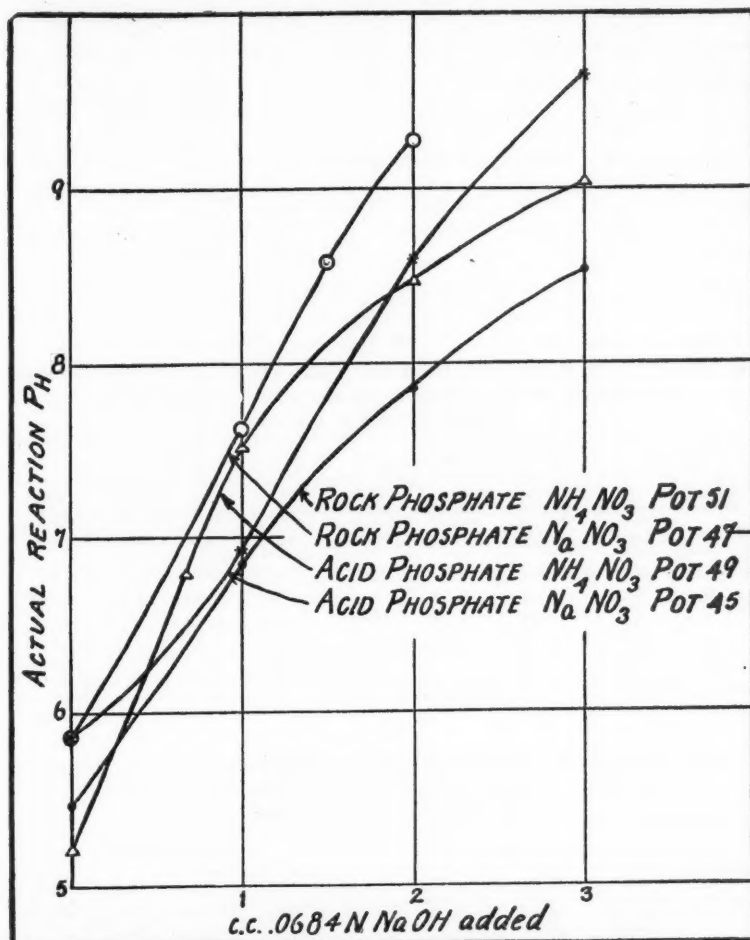
FIG. 8. CURVES SHOWING THE TOTAL ACIDITY OF THE JUICE OF CORN ROOTS IN LEACHED SOIL, IN TERMS OF CUBIC CENTIMETERS OF 0.0684 N NaOH

tions the total acidity was greater in the leached soil. It is also to be observed that the plant juice which had the greatest actual acidity also had the greatest total acidity. This is in accord with the results of Kappen (6) who found that as the actual acidity of the root juices of certain plants increased, the total

TABLE 3

The actual reaction in pH developed by the addition of standard alkali to the juice of the leaves and sheaths of corn plants grown under the conditions indicated. A volume of 10 cc. of juice, centrifuged 10 minutes, was used in each case.

0.0684 N NaOH ADDED	UNLEACHED CULTURES				LEACHED CULTURES			
	Acid phosphate NaNO₃ Pot 37	Rock phosphate NaNO₃ Pot 39	Acid phosphate NH₄NO₃ Pot 41	Rock phosphate NH₄NO₃ Pot 43	Acid phosphate NaNO₃ Pot 45	Rock phosphate NaNO₃ Pot 47	Acid phosphate NH₄NO₃ Pot 49	Rock phosphate NH₄NO₃ Pot 51
cc.	pH	pH	pH	pH	pH	pH	pH	pH
0.0	5.36	5.36	5.31	5.49	5.31	5.31	5.41	5.45
1.0	5.65	5.67	6.03	6.13	5.65	5.62	5.77	5.84
2.0	6.07	5.85	6.88	6.83	5.82	5.92	6.17	6.29
3.0	6.58	6.23	7.76	7.53	6.27	6.15	6.68	6.77
4.0	7.72	6.95	8.48	8.33	6.87	6.59	7.31	7.29
5.0	8.47	8.14	9.10	8.98	8.00	7.46	7.85	7.88
6.0	9.00	8.90			9.00	8.36	8.25	8.44
7.0					9.61	9.04	8.49	8.90
8.0							8.82	

TABLE 4

The actual reaction in pH developed by the addition of standard alkali to the juice of corn stalks grown under the conditions indicated. A volume of 10 cc. of juice centrifuged 10 minutes was used in each case.

0.0684 N. NaOH ADDED	UNLEACHED CULTURES				LEACHED CULTURES			
	Acid phosphate NaNO₃ Pot 37	Rock phosphate NaNO₃ Pot 39	Acid phosphate NH₄NO₃ Pot 41	Rock phosphate NH₄NO₃ Pot 43	Acid phosphate NaNO₃ Pot 45	Rock phosphate NaNO₃ Pot 47	Acid phosphate NH₄NO₃ Pot 49	Rock phosphate NH₄NO₃ Pot 51
cc.	pH	pH	pH	pH	pH	pH	pH	pH
0.0	5.36	5.67	5.95	5.60	5.31	5.62	5.48	5.58
1.0	6.21	6.41	8.25	7.02	6.06	6.29		6.83
2.0	8.19	8.29	9.64	8.04	7.85	7.85		8.04
3.0	9.20	9.56		8.69	9.07	9.04		8.58

TABLE 5

The actual reaction in pH developed by the addition of standard alkali to the juice of corn roots, grown under the conditions indicated, a volume of 10 cc. of juice, centrifuged 10 minutes, was used in each case.

0.0684 N. NaOH ADDED	UNLEACHED CULTURES				LEACHED CULTURES			
	Acid phosphate NaNO₃ Pot 37	Rock phosphate NaNO₃ Pot 39	Acid phosphate NH₄NO₃ Pot 41	Rock phosphate NH₄NO₃ Pot 43	Acid phosphate NaNO₃ Pot 45	Rock phosphate NaNO₃ Pot 47	Acid phosphate NH₄NO₃ Pot 49	Rock phosphate NH₄NO₃ Pot 51
cc.	pH	pH	pH	pH	pH	pH	pH	pH
0.0	6.04	6.02	5.65	5.64	5.88	5.87	5.21	5.48
1.0	7.10	8.47	7.83	7.82	6.92	7.61	7.51	6.87
1.5						8.58		
2.0	8.69	10.10	9.32	9.46	8.56	9.27	8.46	7.88
2.03							9.04	
3.0	9.71				9.64			8.53

acidity also increased.   The data in table 2 indicate that not only does this
hold true for the root juice of corn, but also for the juice of the leaves and
stalks.   In general the results also appear to confirm the findings of Kappen,
namely, that the total acidity of the juice of the tops is greater than that of
the roots.   Further points of interest are the buffer effects indicated by the
varied amounts of alkali required to bring the reaction of the juices from the
litmus to the phenolphthalein color change, and the greater total acidity of
the leaves and stalks when grown with $NaNO_3$ than with NH_4NO_3.

GENERAL DISCUSSION

The data presented in this paper show that lime, leaching, and the form of
phosphate and nitrogen salt, had a marked effect on both the acidity of the
quartz soil solution and of the plant juices, and that this acidity was closely
related to the feeding powers of the plant.   In accordance with the results
obtained, these facts may be explained in the following manner.

Between the acids in the soil, or those present in local zones surrounding the
feeding roots, and the rock phosphate and other salts, there was produced a
condition of equilibrium.   If the plant removed the soluble calcium salts along
with the phosphates, the rock phosphate continued to go into solution.   If,
however, the calcium salts were not removed as rapidly as the phosphate, the
soil became less acid and in consequence the rock phosphate was not so readily
available.   When limestone was used in addition to rock phosphate, the soil
became still more alkaline and the phosphate still more unavailable.   If,
however, the soil was leached, the excess of calcium was removed, the soil
became more acid and hence greater availability of the phosphate followed.
If NH_4NO_3 was used in place of $NaNO_3$ as a source of nitrogen, still greater
acidity appeared in the soil, and the rock phosphate also became still more
available, even, indeed, surpassing the efficiency of acid phosphate in some
cases.

The same explanation may also be given for the behavior of acid phosphate
with the accompanying treatments.   Here, however, on account of the more
acid nature of acid phosphate, leaching and NH_4NO_3 intensified the deficiency
of bases and the resulting acidity, which went to the point of practically pre-
venting plant growth.   On the other hand, it was possible to retard the availa-
bility of acid phosphate by the excessive use of limestone.

Of special interest in these experiments was the marked effect of NH_4NO_3
on the acidity of the soil medium.   This may be explained by one or more of
the following reasons: it may have acted as a physiologically acid salt, it may
have produced acidity by becoming nitrified, and it may have directly increased
the solubility and leaching of calcium bicarbonate.   From the evidence pre-
viously reported (1), and from a study of the soil and plant acidity, it appears
that the behavior of NH_4NO_3 as a physiologically acid salt is an important
factor in relation to its effect in producing acidity of the soil medium.   On
the average, the top portions of the plants were less acid when grown with

NH_4NO_3 than with $NaNO_3$. The roots showed the reverse of this, partaking more of the nature of the reaction of the soil.

In the experiments with corn the actual acidity of the plant juices was directly affected by the acidity of the soil. In this respect the results are in accord with those of Truog and Meacham (8) which indicate that the acidity of the soil is usually directly reflected in the acidity of the plant juices. The total acidity of the juices varied in the same manner as the actual acidity, or hydrogen-ion concentration, which is the same relationship which Kappen (6) found to hold true for the juices of other plants. In the case of the soybean roots, while the hydrogen-ion concentration usually showed a direct relation to the acidity of the soil, the total acidity usually varied in the opposite direction. The explanation for this behavior of soybeans is not apparent.

The data of these experiments strikingly show the power possessed by plants to regulate internal acidity. Marked differences in the acidity of the soil caused only small differences in the acidity of the plant juices—the least variation was caused in the top portions of the plants, and the greatest variation in the roots. This would indicate that the roots are not so well provided with the means of counteracting the acidity as are the portions of the plant where the synthetic processes are taking place. The total acidity of the plant juices varied much more in this respect than the hydrogen ion concentration. These facts only serve to emphasize the power that the plant has in controlling the hydrogen-ion concentration in its juices, even though the total acidity changes considerably.

SUMMARY

The object of the experiments reported in this paper was to study the effect of leaching and certain fertilizer treatments on the acidity of the soil medium and plant juices, and to determine whether the acidity bore any relationship to the feeding power of the plant. For this purpose soybeans and corn were grown in quartz sand cultures which were variously treated with rock phosphate, acid phosphate, limestone, sodium nitrate, and ammonium nitrate. One series of the corn cultures was leached and the other was not. The acidity determinations of the plant juices included both the determination of the concentration of the hydrogen ions and the total acidity. The more important results of the investigations may be summarized as follows:

1. Ground limestone, leaching, and the form of phosphate and nitrogen salt had a marked effect on the acidity of the soil medium and plant juices. The acidity was closely related to the growth and feeding powers of the plants.

2. The use of ground limestone with soybeans increased the amounts of soluble calcium in the soil solution, and hence lessened the actual acidity of the soil and in general the actual acidity of the juices of the plant. In a few cases the limestone appeared to increase the vigor of growth which was accompanied by increased acidity of the plant juices.

3. Leaching the corn cultures removed soluble bases from the soil and hence increased the actual acidity of the soil, and usually also the actual acidity of the juices of the plant.

4. Acid phosphate always produced greater actual acidity or less alkalinity in the soil and usually greater actual acidity in the plant juices than did rock phosphate.

5. Greater actual acidity in the soil and plant juices caused a greater availability of rock phosphate to the plant.

6. Ammonium nitrate compared with sodium nitrate on corn had a marked influence in increasing the actual acidity of the soil and root juices, but an indifferent effect on the acidity of the top portions of the plant.

7. The total acidity of the roots of the soybean plant did not increase with increasing actual acidity. With the corn plant, however, the total acidity increased with the increase of actual acidity in the juices of both the tops and roots.

8. In general, the total acidity of the corn tops was greater than that of the roots.

9. The total acidity of the corn tops was usually greater when $NaNO_3$ was used than when NH_4NO_3 was used.

10. In the two determinations made, ground limestone appeared to lessen the actual acidity of the juice of soybean nodules to a greater extent than it did the actual acidity of the juice of the roots on which the nodules grew. The variation in the actual acidity of the juice of the soybean nodules due to liming was in the same direction as the variation in the actual acidity of the juices of the top portions of the plant.

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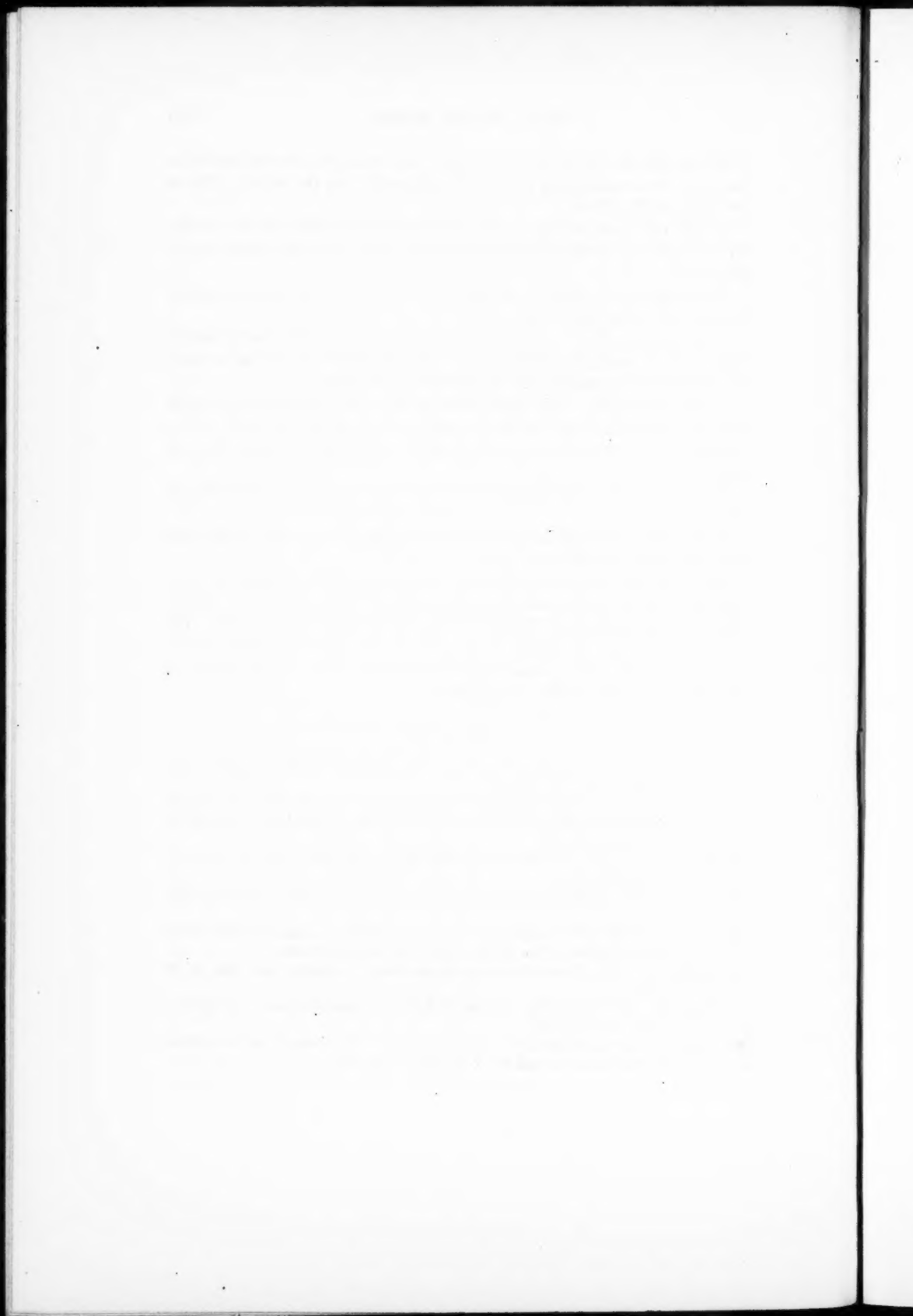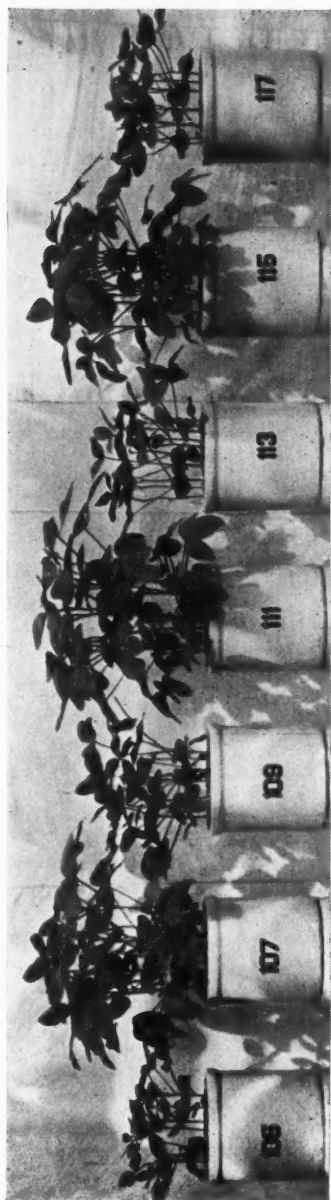
THE GROWTH OF SOYBEANS WITH TREATMENTS AS FOLLOWS:

Pot 105—No phosphorus.
Pot 107—Acid phosphate.
Pot 109—Rock phosphate.
Pot 111—Acid phosphate, 2 tons of limestone.
Pot 113—Rock phosphate, 2 tons of limestone.
Pot 115—Acid phosphate, 10 tons of limestone.
Pot 117—Rock phosphate, 10 tons of limestone.
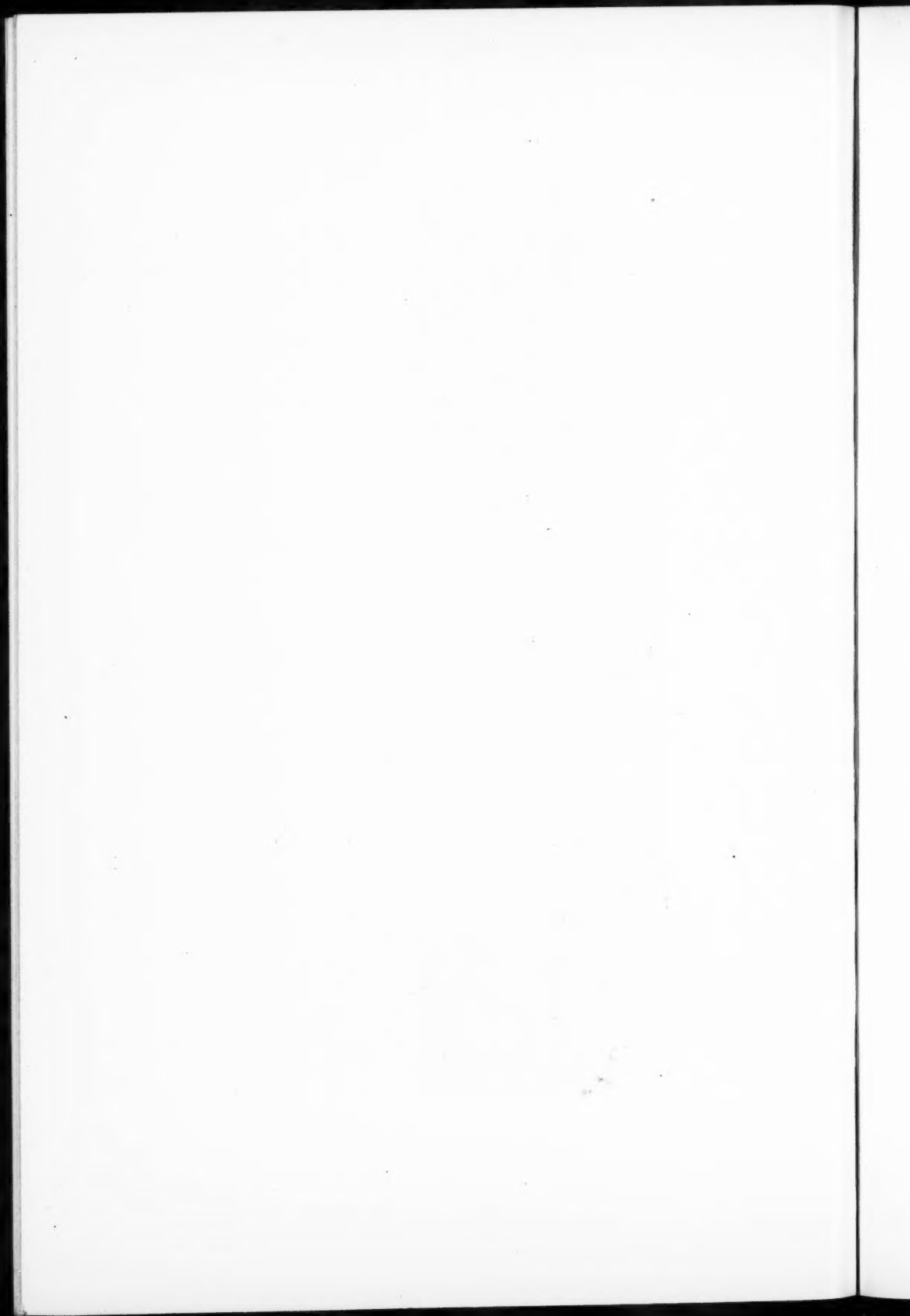
INFLUENCE OF SALTS ON AZOFICATION IN SOIL

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INTRODUCTION

The influence of salts on ammonification (17) and nitrification (18) has been discussed in previous papers. It is the function of this paper to consider the action of the same compounds on azofication in the same soil as that used in the previous work. This was a loose calcarious soil, the physical and chemical analysis of which is given in table 1.

TABLE 1

Physical and Chemical Composition of Soil

PHYSICAL COMPOSITION			CHEMICAL COMPOSITION		
Grade		Per cent	Constituent		Per cent
Coarse sand	above 1 mm........	17.69	Insoluble matter...................		66.69
Fine sand,	1 to 0.03 mm.......	37.39	Potash	(K₂O)........	0.55
Coarse silt,	0.03 to 0.01 mm....	15.19	Soda	(Na₂O).......	0.49
Medium silt,	0.01 to 0.003 mm...	10.36	Lime	(CaO).........	7.41
Fine silt,	003 to 0.001 mm....	10.32	Magnesia	(MgO)........	4.15
Clay	below .001 mm.....		Ferric oxide	(Fe₂O₃)........	2.93
Moisture and loss..................		9.05	Alumina	(Al₂O₃)........	3.49
			Phosphoric pentoxide	(P₂O₅)	0.25
			Sulphur trioxide	(SO₃).........	0.07
			Carbon dioxide	(CO₂).........	7.62
			Humus...........................		2.18
			Total Nitrogen...................		0.15

The soil used, therefore, was a sandy loam very high in acid-soluble constituents, but the water-soluble constituents were not excessive. The calcium and magnesium contents were very high and mainly in the form of the carbonate. The soil was well supplied with phosphorus and potassium and there was a fairly large quantity of iron present. In fact all of the elements of plant-food were present in abundance, with the exception of nitrogen in which this soil was deficient. The soil was very productive and previous work had shown the ammonifying and nitrifying powers of the soil to be about the average for the soils of the arid regions. The nitrogen-fixing powers of the soil were above the average and previous work had shown it to have an intensely interesting bacterial flora.

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PROCEDURE

Several hundred pounds of the soil were thoroughly mixed, stored in a large box, and kept as near field conditions as possible so that all the work could be done on the same soil. As the soil was needed in the work, portions were brought to the laboratory, air-dried in the dark, then weighed in 100-gm. portions into sterile covered tumblers. To each of these was added 1.5 gm. of lactose. The whole was then carefully mixed and the salt in most cases added from a carefully standardized stock solution. This, together with sufficient sterile distilled water to bring the moisture content up to 18 per cent, was thoroughly mixed in the soil. Each series, together with sterile blanks, was incubated at 28° to 30°C. for 21 days. Then nitrogen was determined by the Gunning (2) method, revised to include nitrates. In every case at least four determinations were made with each concentration of the salt, and, in the absence of agreement between determinations, the procedure for that series was repeated so that the results as herein reported are in every case the average of four or more closely agreeing determinations. Hence, experimental error has been reduced to as near a minimum as seemed to be possible in this kind of work.

The solutions of the salts were prepared by weighing gram-molecular quantities of Merck's best grade of the respective salts into 1000 cc. of sterile distilled water and then quantitatively determining the amount present. In those cases in which the analysis showed the concentration wrong, it was corrected, so that we have a definite knowledge of the quantity of salt added to the soil. The varying results reported by different investigators can in many cases, be attributed to the unknown variation in salts added. Solutions thus prepared were then added to the soil in such quantities that the anion and the cation can be directly compared the one with the other. The comparatively insoluble salts—calcium carbonate, calcium sulfate, etc.—were carefully weighed and intimately mixed with the soil. The arranging of the work in this order gives us as nearly absolute results as can be obtained by the present bacteriological methods, and at the same time gives us directly comparable results, which after all is what we have to look for in this work.

The salts tested were the chlorides, nitrates, sulfates, and carbonates of sodium, potassium, calcium, magnesium, manganese, and iron.

INFLUENCE OF SODIUM SALTS

In addition to the essential elements of plant-food applied to a soil, so-called soil amendments are often added. These may influence the physical, chemical, or bacterial properties of the soil. Some substances may alter the physical properties of the soil to such an extent that the bacterial flora is modified. Others may react chemically with constituents within the soil and in so doing liberate substances which can be utilized by the bacteria. Again, there may be a direct stimulation or retarding effect upon the organisms. Within this

field there is much yet to be learned concerning the nitrogen-fixing organisms. We have, however, some information concerning the influence of the so-called alkalies upon the nitrogen-fixing organisms.

A large number of analyses have shown that sodium salts are not necessary for the activity of *Azotobacter* (38) Lipman and Sharp (35) found no stimulation due to the common soil alkalies, sodium chloride, sodium sulfate, or sodium carbonate.

Azotobacter are, however, quite resistant to these compounds, as may be seen from the following report by Barnes and Ali (3):

Mgm. nitrogen fixed per gm. of mannite in nutritive solution inoculated
with alkali soil.. 1.23
Mgm. nitrogen fixed per gm. of mannite in nutritive solution inoculated
with sterile soil.......,........................,............................. 7.80
Mgm. nitrogen fixed per gm. of mannite in nutritive solution inoculated
with normal soil..7.07

Soil which contained sufficient salt to check all vegetation contained nitrogen-fixing organisms. Barnes and Ali hold that salts do not accumulate in the soil in sufficient quantities to kill the nitrogen-fixing organisms, but they are rendered inactive and as soon as the salts are leached from the soil the *Azotobacter* commence to work. Keutner (27) who worked with marine forms of the azofiers, found they would grow and assimilate nitrogen in an 8 per cent solution of sodium chloride. Nitrogen-fixers growing in arable soil would not be as resistant as are those which have become adapted to a medium with a high osmotic pressure, but *Azotobacter* in general appear to be more resistant to alkali salts than are most other soil organisms, for no toxic influence was noted by Lipman (35) until the concentration of sodium chloride in the soil reached 0.5 per cent, sodium sulfate 1.25 per cent, and sodium carbonate 0.4 per cent. They are much more sensitive to sodium in the form of nitrates, for 0.15 per cent stopped their multiplication and probably killed many of them (24). Remy (43) found sodium and potassium carbonate less favorable for nitrogen-fixation than were calcium or magnesium.

So far as the writer is aware, Krainskii (31) is the only worker who has found sodium carbonate more favorable than calcium carbonate. This may have been due to the liberation, by sodium carbonate, of plant-food which was in the soil in an insoluble form but which was essential to the development of *Azotobacter*. Mockeridge (38) has found that the presence of sodium salts is unnecessary and depressing at least to the growth of *Azotobacter*. The beneficial effect ascribed to sodium chloride solution in inoculating agar plates is due to the fact that this liquid is isotonic with the cell content solution, but the sodium hydroxide is a far less advantageous neutralizing agent than is calcium or magnesium carbonate.

The compounds used in this series were sodium chloride, sodium sulfate, sodium nitrate and sodium carbonate. They were used in concentrations 0 to 460 parts of sodium per million of soil. In each concentration the quantity of sodium in the various forms was constant.

The results are reported in table 2 in the form of percentages considering the nitrogen in the soil before incubation as 100 per cent. Each determination is the average of at least four and sometimes several times this number of closely agreeing determinations; hence the results should represent very closely the comparative influence of the various sodium salts upon azofication in this soil.

TABLE 2

Percentages indicating nitrogen fixed in 100 gm. of soil containing 1.5 gm. of finely powdered lactose and varying amounts and forms of sodium salts, after 21 days' incubation

QUANTITY OF SODIUM ADDED	PERCENTAGE OF INITIAL NITROGEN IN SOIL AFTER INCUBATION			
	Sodium chloride	Sodium sulfate	Sodium nitrate	Sodium carbonate
p.p.m.				
0.0	105.7	103.4	101.0	102.1
3.6	106.7	103.2	102.2	102.0
7.2	107.5	103.1	102.9	102.2
14.4	107.0	107.1	103.7	106.0
28.8	108.2	105.7	101.5	105.8
57.5	108.5	107.2	102.0	104.7
115.0	107.3	105.6	99.9	109.5
230.0	105.1	106.4	103.6	105.0
460.0	107.1	108.0	102.8	106.2

Each of the salts stimulate azofication at some concentration. This effect is most pronounced in the case of sodium carbonate and least in the case of sodium nitrate. It will be noted that this soil gained 9.5 per cent of nitrogen in the presence of 115 p.p.m. of sodium in the form of sodium carbonate whereas the same soil in the absence of sodium carbonate gained only 2.1 per cent. The chloride and sulfate also act as a strong stimulant. This is quite different from the results obtained by Lipman and Sharp (35). None of the salts become toxic at the concentrations used. Hence the nitrogen-fixing organisms, as maintained by Barnes and Ali (3), are considerably more resistant to soil alkalies than are the ammonifying or nitrifying organisms.

In this soil the various sodium salts became toxic to the ammonifying and nitrifying organisms at the following concentrations:

SALT	P.P.M. OF SODIUM TOXIC TO:	
	Ammonifier	Nitrifiers
Sodium chloride.....................................	14.4	920.0
Sodium sulfate.....................................	28.8	7.2
Sodium nitrate.....................................	94.2	57.5
Sodium carbonate..................................	2760.0	14.4

With the exception of sodium chloride then, these salts are even more toxic to the nitrifiers than they are to the ammonifiers

Moreover, sodium sulfate failed in every concentration to stimulate either the ammonifiers or nitrifiers whereas sodium carbonate failed in all concentrations to increase nitrification.

INFLUENCE OF POTASSIUM SALTS

Potassium is essential to the higher plants and cannot be replaced entirely by related substances, yet Gerlach and Vogel (14, 15, 16) early reached the conclusion that potassium and magnesium are not essential to the *Azotobacter*. Their results were, however, generally considered erroneous, for while as much nitrogen was fixed in 20 days without as with potassium after 40 days there was no further fixation in the solutions without potassium, but in its presence the nitrogen gain nearly doubled. It was, therefore, argued that the traces of potassium left in the chemicals and dissolved from the glass during sterilization had been enough to permit development for a time. If these elements are essential, it must be in extremely minute quantities, for Vogel (51) using the purest chemicals obtainable, was able to prepare potassium-free media in which the *Azotobacter* developed. He did find, however, that potassium favors their development.

The compounds used in the potassium series were the chloride, sulfate, nitrate and carbonate. The concentration varied from 0 to 782 parts per million of potassium. The results as reported in table 3 are the averages of four or more closely agreeing determinations.

TABLE 3

Percentages indicating nitrogen fixed in 100 gm. of soil containing 1.5 gm. of finely powdered lactose and varying amounts and forms of potassium salts

QUANTITY OF POTASSIUM APPLIED	PERCENTAGE OF INITIAL NITROGEN IN SOIL AFTER INCUBATION			
	Potassium chloride	Potassium sulfate	Potassium nitrate	Potassium carbonate
p.p.m.				
0.0	103.4	100.6	102.5	101.4
6.1	103.4	100.7	101.9	100.7
12.2	103.3	102.2	101.6	100.9
24.4	101.5	105.6	102.2	100.3
48.9	102.5	101.5	103.8	97.2
97.8	101.0	100.2	103.0	96.7
195.5	101.7	102.4	103.0	96.8
391.0	100.2	99.4	101.3	96.6
782.0	100.1	99.5	101.0	96.0

There is a marked difference between the sodium and potassium series. Although potassium is a nutrient it increased azoffcation only when applied to the soil as a sulfate whereas each of the sodium salts stimulated azofication. In this case, however, it must be borne in mind that we are dealing with a soil supplied with considerable available potassium. These data cannot, therefore, be taken to indicate that potassium is without effect upon nitrogen-fixing bacteria.

All except the nitrate of potassium became toxic at some concentration whereas none of the sodium salts became toxic in the concentrations used.

However, with the exception of potassium carbonate the potassium salts used are considerably more toxic to ammonifying and nitrifying organisms than they are to the azofiers.

INFLUENCE OF CALCIUM SALTS

The distribution and physiological efficiency of the nitrogen-fixing organisms, are governed by the physical and chemical properties of the soil, foremost among which is basicity, i.e., its content of calcium or magnesium carbonate (6). Ashby (1) bases his method for obtaining pure cultures of *Azotobacter* upon this property, for he finds that by picking out the crystals of the carbonate from the soil and seeding them into nitrogen-free media the likelihood of obtaining the organism is greatly increased. The addition of calcium carbonate to a soil often increases its azofying power (4). The extent of this increase depends on the lime requirements of the soil and on the fineness of the limestone added (30).

Christensen (7) has suggested that *Azotobacter* may be used as an index of the lime requirements of a soil. The test should include both a search for the organism in the soil and a test of their ability to grow when inoculated into the soil. He and Larson (8) examined more than one hundred soils of known lime requirement. They determined the carbon dioxide set free by acids, the amount of calcium dissolved by an ammonium chloride solution, the behavior of the soil toward litmus, and the biological test. The result of this test was that the biological test agreed with the known condition in 90 per cent of the cases, the ammonium chloride in 50 per cent, the litmus in 40 per cent, and the carbon dioxide failed more often than not to indicate the correct condition of the soil.

Fischer (12) failed to find *Azotobacter* in a heavy loam soil containing only 0.145 per cent of lime, while adjoining limed plots had an *Azotobacter* flora. The quantity of calcium carbonate which must be added to obtain maximum fixation varies with the soil (26).

A West Virginia Dekalb silt loam (7), which required 0.175 per cent of calcium carbonate to render it neutral by the Veitch method, gave greatest nitrogen fixation when 0.375 per cent of calcium carbonate was added. Above this concentration azofication decreased, but when phosphorus was applied with the lime it was not toxic even when present in quantities as great as 0.5 per cent. It is certain that large quantities of calcium carbonate may be present in soil without injury to the azofiers (38).

In many soils lime increases the amount of nitrogen fixed, for Krzemineniewski (33) found limed soil to fix 17.52 mgm. of nitrogen in 10 days, whereas adjoining unlimed soil fixed only 7.15 mgm. in the same time. There is, however, the possibility of applying too large a quantity of the caustic lime and thereby decreasing nitrogen-fixation (28), a condition which has never been experienced in the use of the carbonate.

Von Feilitzen (11), however, found neither a direct relationship between lime content of moor soil and the development of *Azotobacter*, nor a relationship between their development and the reaction of the soil. But this only serves to illustrate the fact that although lime and neutral or slightly alkaline media are essential, they will not insure a rich *Azotobacter* flora in a soil unless all other conditions are favorable.

Gainey (13) found that with a pH value of less than 6.0 there was no fixation of nitrogen in the soils studied by him.

Calcium carbonate and calcium oxide, in addition to furnishing a base which neutralizes the acid form in the metabolic processes of the *Azotobacter*, also furnishes calcium to the organism. Christensen (6) brought out the principle that *Azotobacter* can derive their calcium from dibasic calcium phosphate and some calcium salts of organic acids. They cannot, however, utilize the calcium of tribasic phosphate or of calcium chloride or sulfate.

The compounds which we used in the calcium series were the chloride, nitrate, carbonate and sulfate. The first two were added to the soil according to the usual method from a standard solution, whereas the carbonate and sulfate were weighed into the soil, carefully mixed, and then treated in the ordinary method.

A number of determinations were made in each case and compared with sterile blanks and the results reported in table 4 are the averages of four or more closely agreeing determinations.

Calcium chloride is the only one of the calcium salts which did not increase azofication. In the case of nitrate the increase is very pronounced, a concentration of 200 p.p.m. increased the nitrogen-fixing power ten times. The carbonate is slightly more efficient than the sulfate. It is interesting to note that we have here a soil with over 12 per cent of calcium carbonate and whose nitrogen-fixing powers is increased by the addition of calcium carbonate.

The addition of calcium chloride to this soil also stimulates ammonification but in high concentrations depresses nitrification, calcium sulfate acts in the same way on all three of the groups of organisms, ammonifiers, nitrifiers, and nitrogen fixers. Calcium nitrate, on the other hand, stimulates only the nitrogen fixers.

TABLE 4

Percentages indicating nitrogen fixed in 100 gm. of soil containing 1.5 gm. of finely powdered lactose and varying amounts and forms of calcium salts

AMOUNT OF CALCIUM ADDED	PERCENTAGE OF INITIAL NITROGEN IN SOIL AFTER INCUBATION			
	Calcium chloride	Calcium sulfate	Calcium nitrate	Calcium carbonate
p.p.m.				
0	101.6	101.7	101.2	101.6
3	101.7	101.1	101.5	104.1
6	101.8	101.2	101.1	104.8
12	101.0	102.0	106.1	105.0
25	101.1	102.4	108.8	104.0
50	100.2	102.1	107.9	103.8
100	99.8	104.0	111.2	103.6
200	100.5	103.1	110.2	101.1
400	100.0	104.3	110.1	102.0

The chloride was the only salt used which became toxic to nitrogen fixers in the concentrations used whereas all except calcium carbonates at this concentration were toxic to ammonifiers and all but calcium chloride and sulfate were toxic to the nitrifiers. It, therefore, appears from these results that the azofiers in soil are considerable more resistant to calcium salts than are ammonifiers or nitrifiers.

INFLUENCE OF MAGNESIUM SALTS

The nitrogen-fixing organisms develop normally in the presence of either calcium or magnesium carbonate, but in liquid cultures the film develops earlier and contains less foreign organisms in the presence of magnesium carbonate than in the presence of calcium carbonate.

The actual nitrogen fixed, as reported by Ashby (1), is also greater where magnesium carbonate is used. This he attributes to the suppression of foreign organisms, by the magnesium, especially of the butyric acid ferments.

There is, however, a marked difference in the action of calcium carbonate and magnesium carbonate when they are applied in large quantities. Lipman and Burgess (34) found the calcium carbonate stimulating and never toxic to *Azotobacter chroococcum* in concentrations up to 2 per cent in mannite solution. The magnesium carbonate was sharply toxic in concentrations above 0.1 to 0.2 per cent in such cultures. The calcium salt is without effect when added to most soils up to 1.4 per cent, but the magnesium carbonate is even more toxic in soils than in solutions. Moreover, their work indicated that calcium exerts a protective influence, in both soils and solutions, against the toxic influence of magnesium. The best ratio of calcium to magnesium varies with solution and soil.

The compounds of magnesium used in this work were the chloride, carbonate, nitrate and sulfate. The results obtained are reported in table 5.

The nitrogen fixed in this series is low throughout but it shows an unmistakable stimulation in the case of the chloride, sulfate and nitrate. A point of toxicity was reached with the sulfate, nitrate, and carbonate.

TABLE 5

Percentages indicating nitrogen fixed in 100 gm. of soil containing 1.5 gm. of finely powdered lactose and varying amounts and forms of magnesium salts.

AMOUNT OF MAGNESIUM ADDED	PERCENTAGE OF INITIAL NITROGEN IN SOIL AFTER INCUBATION			
	Magnesium chloride	Magnesium sulfate	Magnesium nitrate	Magnesium carbonate
p.p.m.				
0.0	100.5	102.0	103.2	100.2
1.9	100.5	102.2	102.0	99.1
3.8	100.9	103.7	100.9	99.1
7.6	101.8	101.1	100.4	101.5
15.2	101.8	101.6	99.7	99.1
30.4	101.8	99.8	105.1	99.1
60.8	101.5	102.3	101.1	100.2
121.6	102.7	102.4	101.0	102.1
243.2	100.9	102.0	101.8	99.1

These results indicate that the organisms concerned in nitrogen fixation are more resistant to magnesium salts than are either the ammonifiers or nitrifiers.

INFLUENCE OF MANGANESE SALTS

Manganese is looked upon as one of the most active catalyzers, but the results obtained with it are not always concordant (41, 44).

Some experiments by Skinner and Sullivan (47) demonstrated the fact that manganese acts in various ways as a fertilizer. It is often without influence, occasionally injurious, but usually beneficial, its effect depending apparently upon the composition and character of the soil. The oxidation in soils under treatment with manganese salts was also studied and it was found that an increase in oxidation and growth frequently occurred in aqueous extracts of poor, unproductive soils; but while oxidation was increased in fertile soils, growth was decreased, the plans showing indications of excessive oxidation. Field experiments showed practically no effect from the manganese salts, but the soil was acid, a condition which may have accounted to a considerable degree for the nature of the results.

It is suggested that when the action of manganese is beneficial, it is probably due (a) to the increased oxidation produced in the plant roots whereby the plant is stimulated to greater activity and to increased absorption of the material useful for its growth and general metabolism; (b) to the stimulation of the activity of microörganisms in the soil; (c) to an increased oxidation within the soil.

The same authors suggest that when large applications of manganese have been found to be injurious, the injury is undoubtedly due to the "excessive stimulation and excessive oxidation in microörganisms and in the plant with a resulting change in the biochemical activities of plant and microörganisms and in the conditions of inorganic and organic soil constituents, the ultimate result of which change is injurious to the growing crop."

An Italian investigator (10) found that manganese carbonate added to the soil with a natural phosphocarbonate greatly increased the yield of wheat and alfalfa, whereas Pfeiffer and Blanck (41) found that manganese caused an increased assimilation of nutritive substances from the soil.

Although the addition of manganese to a soil often increases the nitrogen content of the crop (46) it does not increase the manganese content (22), thus indicating that its action is mainly on the biological transformation of nitrogen and possibly phosphorus which is going on in the soil.

TABLE 6

Percentages indicating nitrogen fixed in 100 gm. of soil containing 1.5 gm. of finely powdered lactose and varying amounts and forms of manganese salts

AMOUNT OF MANGANESE	PERCENTAGE OF INITIAL NITROGEN IN SOIL AFTER INCUBATION			
	Manganous chloride	Manganous sulfate	Manganous nitrate	Manganous carbonate
p.p.m.				
0.0	101.4	101.0	100.8	101.3
4.3	102.1	103.4	98.6	100.4
8.6	102.7	98.6	98.1	101.3
17.2	103.7	98.6	99.3	100.3
34.4	102.9	98.5	100.2	100.1
68.8	102.3	101.5	98.6	100.3
137.6	100.7	101.6	98.0	100.9
275.2	100.8	101.2	103.0	101.3
550.4	100.9	98.8	102.9	100.4

While not essential to bacteria, manganese is an active catalyzer (20) in increasing proportions up to 6 mgm. per 100 cc. of media. Above this conncetration the reaction falls off rapidly and at 20 mgm. it is less than in the absence of manganese. It is oxidized by *Azotobacter*, and in the proportions of 1 to 200,000 parts of soil it is an active stimulant. Olaru (39) considers it likely that the increased yield obtained after the application of manganese compounds to a soil is due to its accelerating the action of the nitrogen-fixing organisms. He found that in the right concentration manganese has a very favorable influence upon *Azotobacter chroococcum* (40). The results obtained in our experiments with manganese are given in table 6.

The chloride and nitrate are the only ones which stimulate the azofiers and in the case of these it is very weak as compared with the action of manganese upon the ammonifiers and nitrifiers which in appropriate concentrations is very pronounced. These results indicate that the beneficial results from the use of manganese is due mainly to their influence upon the ammonifiers and nitrifiers and not the nitrogen fixers. Hence they would have to be

classed as mere soil stimulants which do not increase the total soil fertility but render more available some constituents which are probably, the nitrogen, phosphorus and potassium (19). However, the toxicity of the manganese compounds are not so great for the azofiers as they are for the ammonifiers and nitrifiers.

INFLUENCE OF IRON SALTS

Iron (28) is essential to the nitrogen-fixing microörganism, and either the ferric or ferrous sulfate is especially beneficial (29). Rosing (45) found the amount of nitrogen fixed increased from 2.23 mgm. to 10.3 mgm. per gram of mannite when iron sulfate was added to the cultural media. This is due, in a great degree, to the iron which serves as food for the organism, yet its colloidal nature may play a part, for both organic and inorganic colloidal substances have an especially favorable action on *Azotobacter* although the action of the inorganic colloids is fully manifest only in the presence of organic colloids (42). If used alone, large quantities of the ferric hydroxide are essential for the maximum effect, but in the presence of organic colloids, very small quantities of iron are effective. This has been attributed to the action

TABLE 7

Percentages indicating nitrogen fixed in 100 gm. of soil containing 1.5 gm. of finely powdered lactose and varying amounts and forms of iron salts

AMOUNT OF IRON ADDED	PERCENTAGE OF INITIAL NITROGEN IN SOIL AFTER INCUBATION			
	Ferric chloride	Ferric sulfate	Ferric nitrate	Ferric carbonate
p.p.m.				
0.0	102.4	102.5	106.7	101.4
2.9	100.8	102.6	108.7	102.7
5.8	101.5	102.5	106.3	101.8
11.6	103.3	102.9	106.8	103.2
23.2	103.3	102.1	108.0	101.0
46.5	103.3	101.6	105.9	100.0
93.0	104.2	101.7	107.3	99.4
186.0	104.2	100.4	106.7	100.0
372.3	106.8	101.1	95.5	100.2

of the colloidal iron which absorbs the nitrogen and oxygen of the air and brings them into more intimate contact with the *Azotobacter* (48). This would not only accelerate the normal processes of the aerobic *Azotobacter* by furnishing them with nitrogen and oxygen but it would tend to suppress the anaerobic processes which are extremely wasteful of the food.

The compounds used in this series were ferric chloride, ferric sulfate, ferric nitrate and ferrous carbonate. All except the carbonate were added to the soil in solution. The carbonate was added in the form of a dry powder and carefully mixed with the soil. Considerable difficulty was experienced in obtaining duplicate determinations to agree when the sulfate was applied to the soil and the results as reported for sulfate represent the average of eight sets of determinations. The chloride, nitrate, and carbonate represent the average of four closely agreeing sets of determinations. The results are given in table 7.

All of the iron compounds stimulated nitrogen fixation. The stimulation is most pronounced in the case of the chloride and least in the case of the sul-

fate. The influence upon this group of organisms is not nearly so pronounced as the influence of iron salts on ammonifying and nitrifying microörganisms. The stimulation of the three groups of soil organisms together with results obtained when higher plants are treated with iron salts (19) make it certain that the increased yield obtained from the use of iron salts is due in a very marked degree to the action of these compounds upon soil microörganisms.

INFLUENCE OF CHLORIDES

So far in this discussion we have been comparing the action of compounds having the same electro-positive ion but various electro-negative ions. Hence, the results considered have given us an insight into the influence of the anions Cl, SO_4, NO_3, and CO_3, upon the nitrifying efficiency of the soil. It is there-

TABLE 8

Percentages indicating nitrogen fixed in 100 gm. of soil containing 1.5 gm. of finely powdered lactose and varying amounts and forms of chlorids

AMOUNT OF CHLORIDE	PERCENTAGE OF INITIAL NITROGEN IN SOIL AFTER INCUBATION					
	Sodium chloride	Potassium chloride	Calcium chloride	Magnesium chloride	Manganous chloride	Ferric chloride
p.p.m.						
0.0	105.7	103.4	101.6	100.5	101.4	102.4
5.54	106.7	103.4	101.7	100.5	102.1	100.8
11.08	107.5	103.3	101.8	100.7	102.7	101.5
22.16	107.0	101.5	101.0	101.8	103.7	103.3
44.32	108.2	102.5	101.1	101.8	102.9	103.3
88.65	108.5	101.0	100.2	101.8	102.3	103.3
177.30	107.3	101.7	99.8	101.5	100.7	104.2
354.60	105.1	100.2	100.5	102.7	100.8	104.2
709.20	107.1	100.1	100.0	100.9	100.9	106.8

fore interesting to compare the compounds which have a constant anion and various cations. This is done in table 8. In this series we have the chlorides of sodium, potassium, magnesium, calcium, manganese, and iron. The experiment was so arranged that equivalent quantities of chlorine in the various forms were applied to 100 gm. of soil. Each reported result is the average of four or more closely agreeing determinations.

It is evident that all of the chlorides with the exception of calcium chloride and possibly potassium chloride stimulate the azofiers of the soil. This is not due alone to the electro-negative ion for the extent of stimulation varies widely with the anion. It is very pronounced where ferric chloride has been applied to the soil and is barely perceptible where potassium chloride has been used. Moreover, the concentration at which maximum stimulation occurs varies with the specific salt. These concentrations are as follows:

	parts of Cl per million of soil mixture
Sodium chloride	44
Calcium chloride	11
Magnesium chloride	.354
Manganous chloride	22
Ferric chloride	.709

Three of the compounds—potassium, calcium and manganous chloride became toxic at the concentrations tested whereas the others did not.

The results as a whole, however, bears out the conclusion that the benefical effect of the chlorides were due in no small measure to their action upon soil microörganism which in turn render more plant food available.

INFLUENCE OF SULFATES

The results obtained with the various sulfates are summarized in table 9.

TABLE 9

Percentages indicating nitrogen fixed in 100 gm. of soil containing 1.5 gm. of finely powdered lactose and varying amounts and forms of sulfates

AMOUNT OF SULFATE	PERCENTAGE OF INITIAL NITROGEN IN SOIL AFTER INCUBATION					
	Sodium sulfate	Potassium sulfate	Calcium sulfate	Magnesium sulfate	Manganous sulfate	Ferric sulfate
p.p.m.						
0.0	103.4	100.6	101.7	102.0	101.0	102.5
7.5	103.2	100.7	101.1	102.2	103.4	102.6
15.0	103.1	102.2	101.2	103.7	98.6	102.5
30.0	107.1	105.6	102.0	101.1	98.6	102.9
60.0	105.7	101.5	102.4	101.6	98.5	102.1
120.1	107.2	100.2	102.1	99.8	101.5	101.6
240.2	105.6	102.4	104.0	102.3	101.6	101.7
480.3	106.4	99.4	103.1	102.4	101.2	100.4
960.6	108.0	99.5	104.3	102.0	98.8	101.1

Magnesium sulfate and ferric sulfate fail to stimulate azofication in any of the concentrations tested. All of the other sulfates have a pronounced stimulating influence at some concentration. At a concentration of 960.6 parts of sulfate per million of soil mixture the total nitrogen of the soil was increased 2.6 per cent in the case of calcium sulfate, 4.6 per cent in the case of sulfate of sodium and 5 per cent in the case of potassium sulfate. These compounds may, therefore, actually increase the soil fertility aside from the sulfur and potassium carried. Moreover, the sodium and calcium sulfate can be looked upon other than as stimulants, for in addition to the phosphorus, potassium and nitrogen which they render available they also increase the total nitrogen supply of the soil through their action upon the azofiers.

Potassium sulfate acts quite differently from the sodium in that the former became toxic in the higher concentrations whereas the latter did not. This same phenomenon appeared in the ammonifying and nitrifying tests when potassium sulfate was considerable more toxic than sodium sulfate. However, the resistance of the azofiers is greater to these salts than are the other classes of microörganisms. Ferric sulfate also becomes toxic but at a concentration much greater than that at which it becomes toxic to other soil organisms. It appears probable that the beneficial action of these various salts towards azofiers may be due in a measure to their suppressing of other species which compete with the azofiers for the limited supply of organic carbon in the soil.

INFLUENCE OF NITRATES

A marked difference between the azofiers and higher plants and other bacteria is that they possess the power of obtaining their nitrogen from the air, but in the presence of combined nitrogen they obtain but little from the air (50). Lipman (36), Stranak (50), Heinze (23), and Stoklasa (49) found that small quantities of nitrates stimulated *Azotobacter*, whereas large quantities discourage nitrogen-fixation since the organisms live on the nitrates. This is the case whether the nitrates are added to the soil or to the solution in which nitrogen-fixation is taking place. Coleman (9) considers this action as due to several different factors, namely, (a) a direct toxic action of the salt, (b) antagonism of other organisms which it favors, (c) the using up of the energy supply by these organisms, and (d) the discouragement of fixation by the use of sodium nitrate. The last would seem to be the most important factor when viewed in connection with the following results reported by Hills (21):

TREATMENT NITRATE	RELATIVE NUMBER* OF ORGANISMS			RELATIVE PER CENT OF NITROGEN FIXED			
				Sterilized soil		Unsterilized soil	
	KNO_3	$NaNO_3$	$Ca(NO_3)2$	$NaNO_3$	$Ca(NO_3)2$	$NaNO_3$	$Ca(NO_3)2$
mgm.							
0	100	100	100	100	100	100	100
10	348	191	362	100	105	240	219
50	8,210	3,150	4,528	342	371	500	444
150	12	117	763				
200	0	0	0	352	467	879	557

* The number of organisms developing and nitrogen fixed in the one receiving no nitrate is taken as 100 per cent.

It is quite evident from these results that although nitrates cause more active multiplications of *Azotobacter*, it greatly reduces their physiological efficiency. The organisms used by Hills had probably grown for a long time on media poor in nitrogen, and their ability to fix nitrogen was, therefore, high, But would they continue to exert this power if grown on media rich in nitrogen? The evidence points strongly to the conclusion that they would not.

Bonazzi (5) even argues from a recalculation of Hills results where he used *Azotobacter chroococcum* in synthetic media that nitrates either in the form of sodium nitrate or ammonium nitrate cause a very appreciable loss of nitrogen either as free nitrogen or as a volatile nitrogenous compound. He further considers it probable that whereas *Azotobacter chroococcum* may be a fixer of atmospheric nitrogen under such conditions as we may call "normal." i.e., is the absence of fixed nitrogen and a denitrifer when such conditions are changed so it may feed upon nitrates.

Nitrates and ammonium sulfate are rather effective in stimulating nitrogen-fixation when the *Azotobacter* are grown in connection with the cellulose ferments (37). Even here, however, large quantities have been found to decrease this power. In pure cultures ammonium sulfate (32, 36) seriously retards nitrogen-fixation, whereas the nitrogen of humus, even in large quantities, appears to have no serious retarding influence. Nevertheless, a high nitrogen content of soil seems to be unfavorable to a vigorous nitrogen-fixation whether this would be the case where the nitrate content of the soil is kept low but the readily decomposable nitrogen high, is yet to be answered. Hiltner and Stormer (25) consider that when the nitrogen content of the soil passes beyond a certain limit, the decay bacteria increase rapidly, and in the struggle for existence they are able to suppress the more slowly growing *Azotobacter*. This latter contention would not seem to be borne out by our results for we find that the nitrates become toxic to the ammonifiers and usually to the nitrifiers before they were toxic to the azofiers.

The compounds used in this series were sodium nitrate, potassium nitrate, calcium nitrate, magnesium nitrate, manganous nitrate, and ferric nitrate.

TABLE 10

Percentages indicating nitrogen fixed in 100 gm. of soil containing 1.5 gm. of finely powdered lactose and varying amounts and forms of nitrate salts

AMOUNT OF NITRATE ADDED	PERCENTAGE OF INITIAL NITROGEN IN SOIL AFTER INCUBATION					
	Sodium nitrate	Potassium nitrate	Manganous nitrate	Calcium nitrate	Magnesium nitrate	Ferric nitrate
p.p.m.						
0.0	101.0	102.5	100.8	101.2	103.2	106.7
9.7	102.2	101.9	99.6	101.5	102.0	108.7
19.4	102.9	101.6	98.1	101.1	100.9	106.3
38.8	103.7	102.2	99.3	106.1	100.4	106.8
77.6	101.5	103.8	100.2	108.8	99.7	108.0
155.2	102.0	103.0	98.6	107.9	105.1	105.9
310.4	99.9	103.0	98.0	111.2	101.1	107.3
620.8	103.6	101.0	103.0	110.2	101.0	106.7
1,241.6	100.8	101.0	102.9	110.1	101.8	95.5

The quantity added to the soil was such that in each case equivalent quantities of nitrate in the various forms were added to the soil. Hence, the varying factor is the electro-positive ion, and the electro-negative remained the same in each case. The results are given in table 10.

There is an unmistakable fixation of nitrogen in each of these soils in the presence of nitrates. This fixation is even greater in the presence of the nitrate and lactose than it is in the presence of lactose alone. Thus showing that small quantities of nitrates in a soil stimulate nitrogen fixation. The calcium salt is considerably more efficient than are the sodium or potassium salts. The total quantity of nitrogen in this soil was only 0.15 per cent. But the addition of 2 per cent of dried blood plus the various forms of nitric nitrogen stimulated fixation to even a greater extent as may be seen by the results given in table 11.

Sodium nitrate-treated soil shows only a small gain in nitrogen, whereas potassium nitrate-treated soil shows an actual loss. But in the presence of calcium, magnesium or iron nitrate there was a fixation of four to eight times that actually fixed in the untreated soil.

Every one of these soils showed a loss of nitrates at the end of the incubation period but it had been transformed into protein nitrogen and not lost as has been interpreted by some workers. Moreover, these results make it clear that the azofiers in the soil are injured sooner by the potassium and sodium nitrate than by other forms of nitric nitrogen. These results are quite different from those obtained in solutions where the areation would not be favorable for nitrogen fixation. But the results indicate that in a normal calcareous

TABLE 11

Quantity of nitrogen obtained from 100 gm. of soil receiving various treatments

TREATMENT	NITROGEN IN 100 GM OF SOIL	EXCESS IN NITRATE TREATED SOIL	GAIN OR LOSS IN NITROGEN OVER SOIL RECEIVING NO NITRATE
	mgm.	*mgm.*	*mgm*
Dried blood. no nitrate..............................	333.9		
Dried blood, 84.06 mgm. of nitrogen as sodium nitrate..	419.3	85.4	1.34
Dried blood, 84.06 mgm. of nitric nitrogen as calcium nitrate..	460.5	126.6	42.54
Dried blood, 84.06 mgm. of nitric nitrogen as ferric nitrate..	455.0	121.1	37.04
Dried blood, 84.06 mgm. of nitric nitrogen as magnesium nitrate.................................	466.5	132.6	48.54
Dried blood, 84.06 mgm. of nitric nitrogen as manganous nitrate.................................	443.1	109.2	25.14
Dried blood, 84.06 mgm. of nitric nitrogen as potassium nitrate.................................	412.0	78.1	− 5.96

soil the losses from dentrification on the application of reasonable quantities of nitrate is zero. Moreover, in place of retarding beneficial bacterial activities nitrates actually increases them.

INFLUENCE OF CARBONATES

The compounds used in this series were the carbonates of sodium, potassium, calcium, magnesium, manganese and iron. The results are given in table 12.

Sodium, calcium and ferric carbonate are pronounced stimulants of the azofiers whereas potassium, magnesium and manganous carbonate are without effect. This effect is quite different from that upon the ammonifiers which were stimulated by all of the carbonates. Sodium, potassium, or calcium carbonates did not stimulate the nitrifiers in this soil.

Potassium, magnesium and ferric carbonate became toxic at some of the concentrations used but at higher concentrations than at which they became toxic to the other groups of organisms..

TABLE 12

Percentages indicating nitrogen fixed in 100 gm. of soil containing 1.5 gm. of finely powdered lactose and varying amounts and forms of carbonates

AMOUNT OF CARBONATE ADDED	PERCENTAGE OF INITIAL NITROGEN IN SOIL AFTER INCUBATION					
	Sodium carbonate	Potassium carbonate	Calcium carbonate	Magnesium carbonate	Manganous carbonate	Ferric carbonate
p.p.m.						
0.0	102.2	101.4	101.6	100.2	101.3	101.4
4.7	102.0	100.7	104.1	99.1	100.4	102.7
9.4	102.2	100.9	104.8	99.1	101.3	101.8
18.7	106.0	100.3	105.0	101.5	100.3	103.2
37.5	105.8	97.2	104.0	99.1	100.1	101.0
75.0	104.7	96.7	103.8	99.1	100.3	100.0
150.0	109.5	96.8	103.6	100.2	100.9	99.4
300.0	105.0	96.6	101.1	102.1	101.3	100.3
600.0	106.2	96.0	102.0	99.1	100.4	99.3

SUMMARY

The toxicity of the chlorides, nitrates, sulfates and carbonates of sodium, potassium, calcium, magnesium, manganese and iron as determined by nitrogen fixation is governed by the specific salt and not by the electronegative ion, as was the case with the ammonifers. In this regards the azofiers are similar to the nitrifiers.

These salts are all less toxic to azofiers in the soil tested than they are to the ammonifers or nitrifers.

The quantity of a salt which can be applied to a soil without decreasing the nitrogen gains varies with the salt. None of the sodium salts were toxic when 460 p.p.m. of sodium in the form of the various salt was applied to the soil. Calcium nitrate, sulfate and carbonate at 400 p.p.m., magnesium chloride and sulfate at 243 p.p.m., manganous nitrate at 550 p.p.m and ferric chloride at 372 p.p.m., were not toxic. The remaining salts became toxic at some concentration tested, in the following order:

1. $MgCO_3$
2. $Mg(NO_3)_2$
3. K_2CO_3
4. $FeCO_3$
5. $MnCO_3$

6. $Fe(NO_3)_3$
7. $Fe_2(SO_4)_3$
8. $CaCl_2$
9. $MnCl_2$

10. KCl
11. K_2SO_4
12. KNO_3
13. $MnSO_4$

KCl, K_2CO_3, $MnCO_3$ and $Fe_2(SO_4)_3$ failed to stimulate the nitrogen-fixing organisms in any of the concentrations tested. All the others stimulated the organisms in the following order:

1. $Ca(NO_3)_2$	6. $CaCO_3$	11. $MnCl_3$	16. $MgCO_3$
2. Na_2CO_3	7. $NaCl$	12. $Mn(NO_3)_2$	17. $FeCO_3$
3. K_2SO_4	8. $NaNO_3$	13. $MgCl_2$	18. $MgSO_4$
4. Na_2SO_4	9. $MnSO_4$	14. $Fe(NO_3)_3$	19. KNO_3
5. $FeCl_3$	10. $CaSO_4$	15. $Mg(NO_3)_2$	20. $CaCl_2$

The common soil alkalies would have to be present in soil in sufficient quantities to greatly retard ammonification, nitrification and plant growth before they would retard nitrogen fixation, provided the soil was not acid and was supplied with the necessary nutrients for the functioning of the azofiers. The azofiers are more resistant to these salts than are the ammonifiers, nitrifiers or most higher plants.

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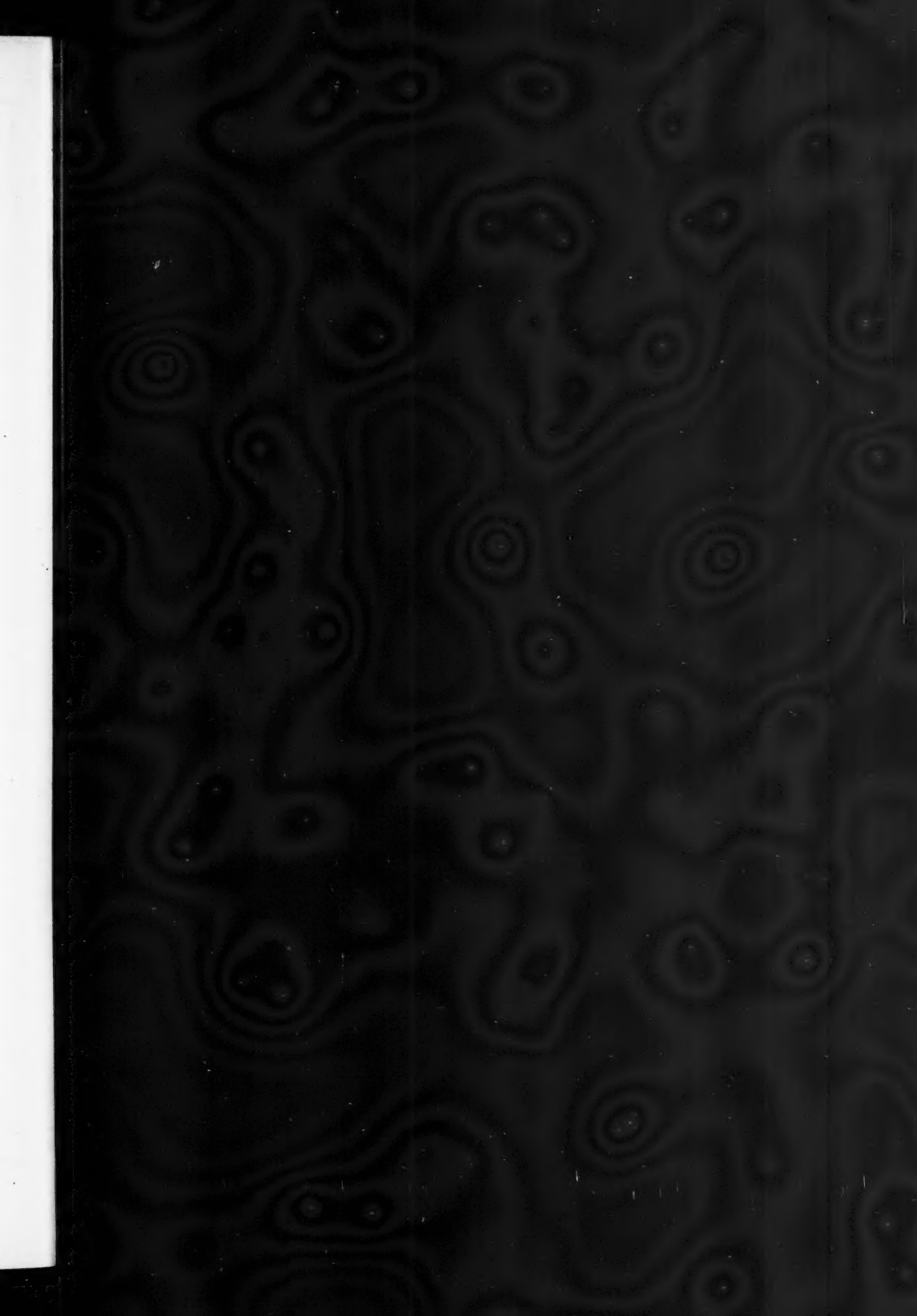*For Germany:* Friedländer & Sohn, Buchhandlung, Carlstrasse 11, Berlin NW. 6.

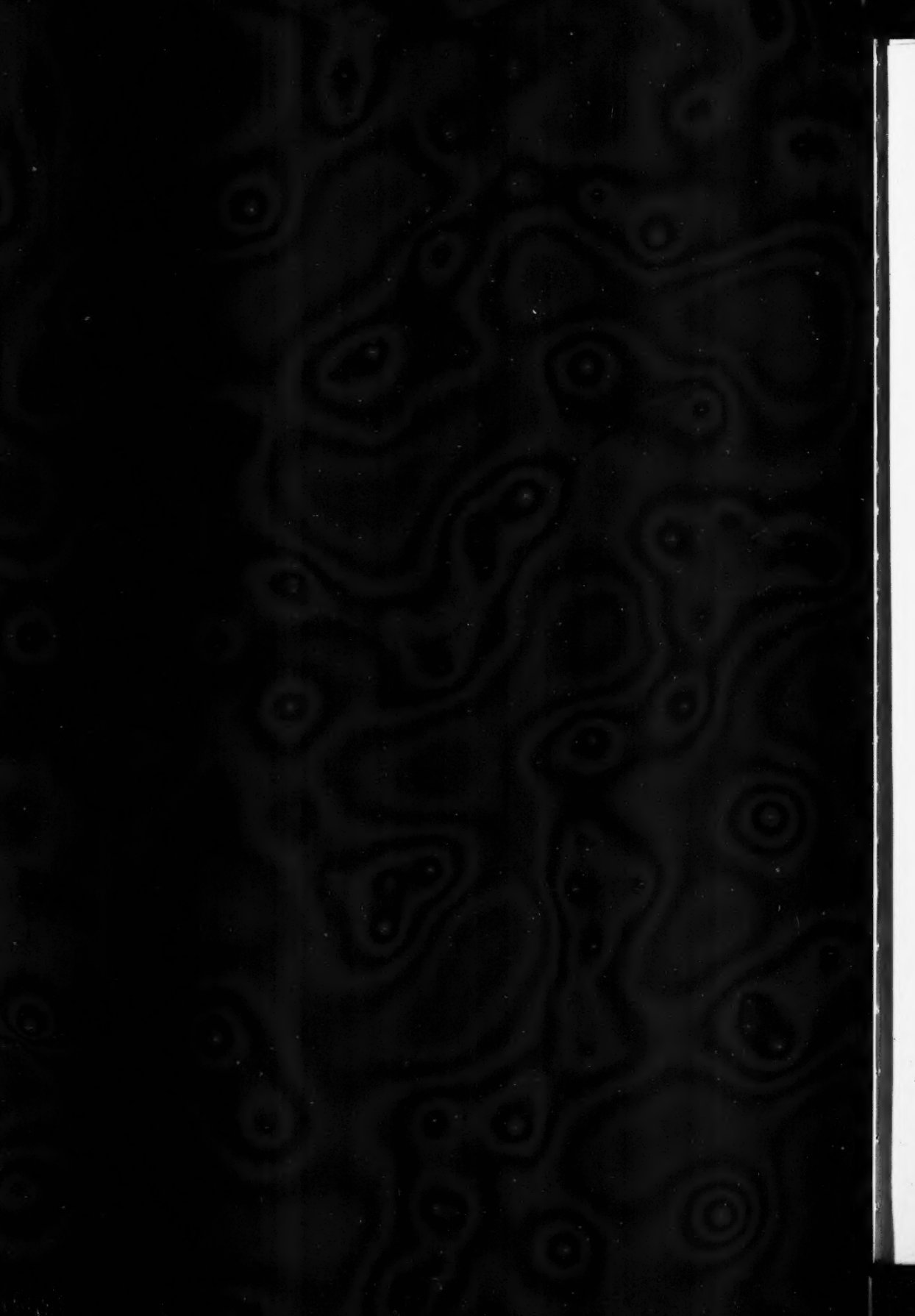*For Holland:* Scheltema & Holkema, Rokin 74–76, Amsterdam.

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No claims for copies lost in the mails will be allowed unless such claims are received within 30 days (domestic), and 90 days (foreign), of the date of issue. Claimants must state that the publication was not delivered at their recorded address. The publishers will not be responsible for loss due to change of address unless notification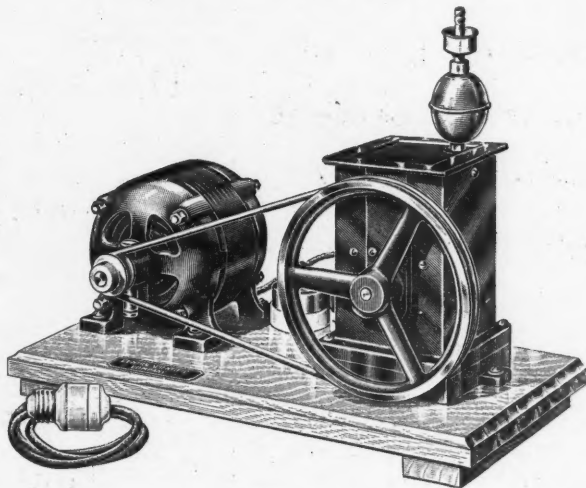 is received at least two weeks in advance of issue.